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WIND TUNNEL FACILITIES AT THE JET PROPULSION LABORATORY

[8]

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PREFACE

The Jet Propulsion Laboratory (JPL) is a research and development center located in Pasadena, California and operated by the California Institute of Technology for the National Aeronautics and Space Administration (NASA). This report describes the wind tunnel facilities presently available at JPL for NASA and military-service testing purposes.

Distance to Jet Propulsion Laboratory from:

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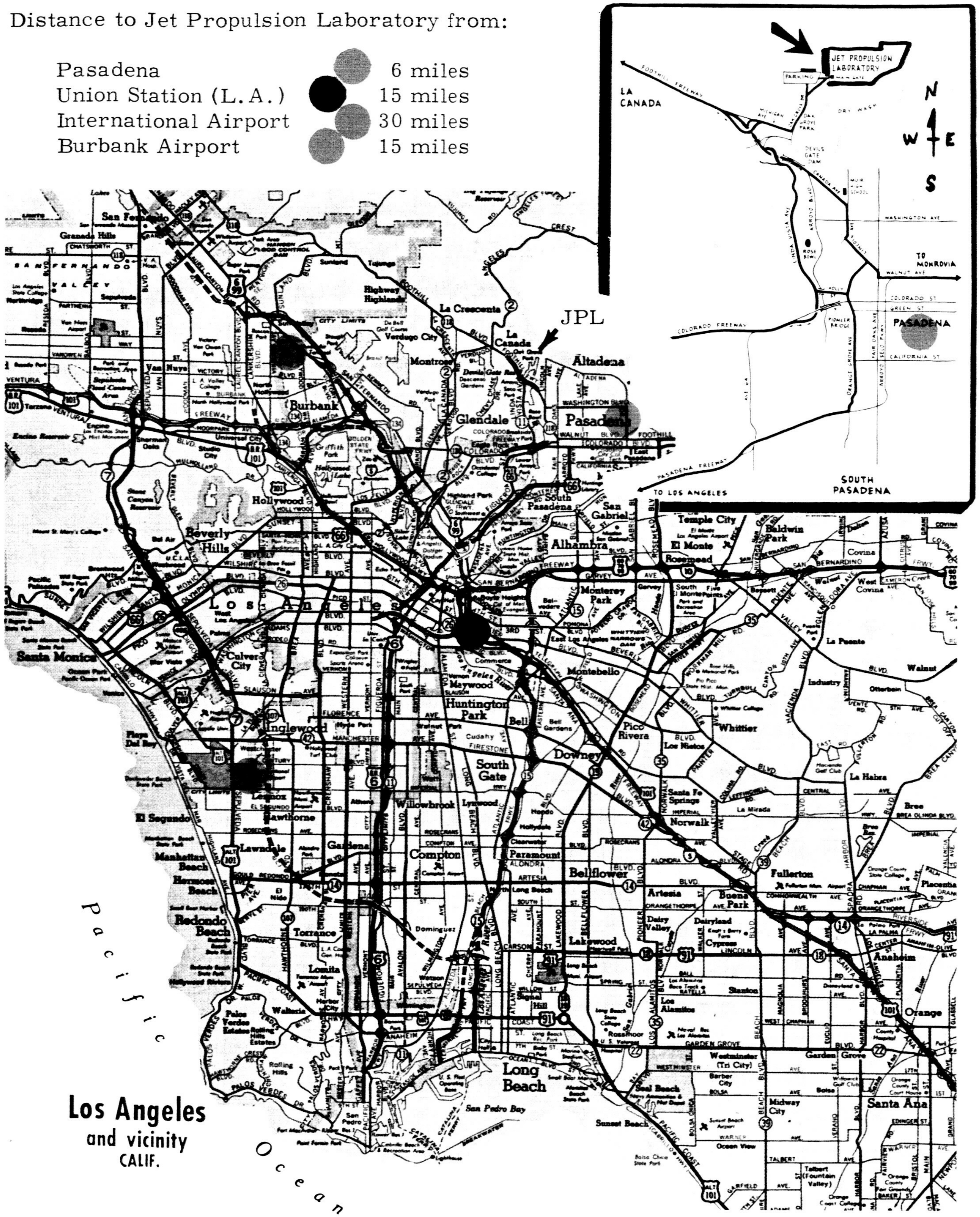

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Route to Jet Propulsion Laboratory
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FIGURES

FIGURES (Cont'd)

A. INTRODUCTION

I. General Description of the Wind Tunnels

The present wind tunnel facilities include a 20-in. supersonic wind tunnel (SWT) with a Mach-number range of 1.3 to 5.6 and a 21-in. hypersonic wind tunnel (HWT) with a Mach-number range of 4.1 to 11.0. The geometric size of the 20-in. SWT test section is 18-in. wide by 20-in. high, while the 21-in. HWT has a test section which is 21 inches wide at the downstream end (the side walls each diverge at about 1/2 deg) and 15 to 28-in. high (adjustable). Both wind tunnels are of the continuous-flow, variable-density type and each utilizes a two-dimensional flexible nozzle* which can provide an "infinite" choice of test-section Mach numbers within a specified range. Several views of each tunnel are shown in Fig. A-1 and A-2.

II. Test Section Size

The portion of the geometric test section that can be used for reliable aerodynamic testing is a function of the model geometry, tunnel Mach number, and Reynolds number. The model-sizing information which follows is not necessarily unique with JPL but has been verified experimentally in the 20-in. SWT.

The maximum permissible model frontal area which will permit establishment of flow in the test section is larger than the maximum area which will

*It should be noted that the 21-in. HWT utilizes a pair of solid throat blocks (with adjustable throat height) which remain dimensionally stable for all practical purposes in spite of the heated high-pressure supply air. The philosophy surrounding the design of the 21-in. HWT is described in Ref. 1.

allow the formation of a proper model wake. The comparison of these two areas for spherical models is shown in Fig. A-3. In order to give a rule-of-thumb for converting these areas to models of different shapes, such as cones (σ = cone semi-vertex angle), a relationship is given in Fig. A-4. In general, as the drag coefficient of a model is decreased, the frontal area may be increased and yet retain the flow establishment or proper wake-formation criteria.

Once the model frontal area has been decided upon, it is possible to determine the maximum model length. In order to guide the user in estimating the permissible model length, various pertinent dimensional quantities for the test section are presented in Fig. A-5. A typical requirement in a test where the model is to be pitched and/or yawed is that the model not enter the tunnel boundary layer. The pitot-pressure core size is $h_g - 2\delta$ by $w_g - 2\delta$. This relationship indicates a core that is 16.1-in. wide by 18.1-in. high in the SWT at $M = 1.4$ and a core that is 10.3-in. wide by 14.3-in. high in the HWT at $M = 10.1$. It must be noted for the HWT that although the total-temperature (T_o) core is approximately equal to the pitot-pressure (P_o') core at the lower Mach numbers, at $M = 10.1$ it is considerably less than the pitot-pressure core (representative pitot-pressure and total-temperature profiles are shown in Sect. C of this report).

When investigating the possibility of shock waves reflecting back to the model it should be assumed that the reflection plane for weak to medium strength (no appreciable boundary layer separation) shock waves is approximately at a distance δ^* from the physical walls of the tunnel.

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III. Scheduling Information

After JPL concurs with the Contractor that his program can be and should be undertaken in the JPL facility, the Contractor is advised to request tunnel time through his Weapons System Project Officer. The cognizant officer's office in each service, after receiving the specific program requests from the various Weapons System Project Officers, must then make the time allocations based on overall priorities of the projects within that service. These requests are then processed through the Aircraft and Missile Projects Allocation and Priority Group and the request forwarded to the Director of NASA (Attention Director of the Office of Advanced Research and Technology). NASA Headquarters checks with JPL for concurrence and recommendations prior to granting internal approval for the investigation. This arrangement permits the individual service, the Department of Defense, and NASA each to exercise some control over the test allocation based on reasons of priority, work load, and facility suitability.

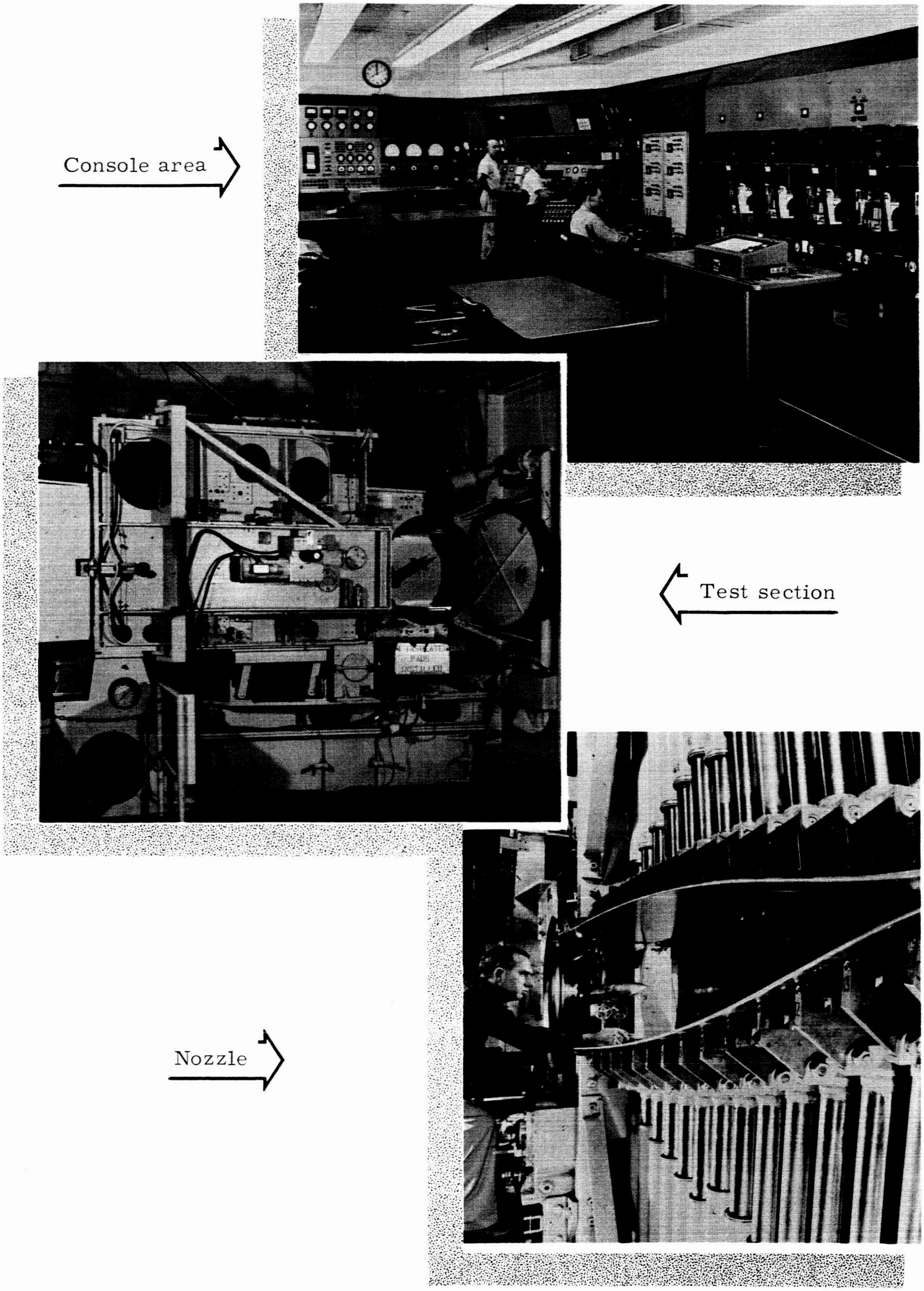
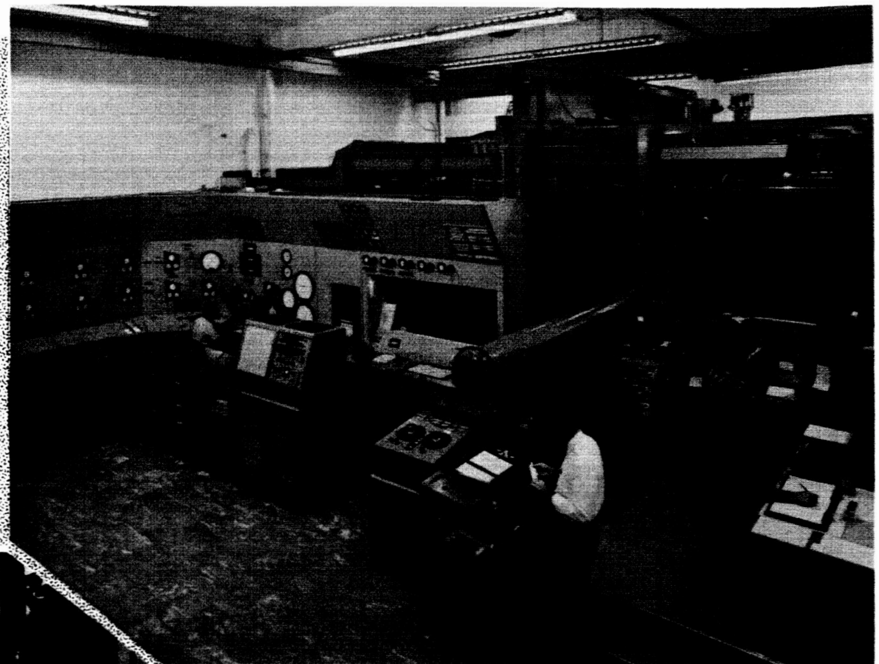
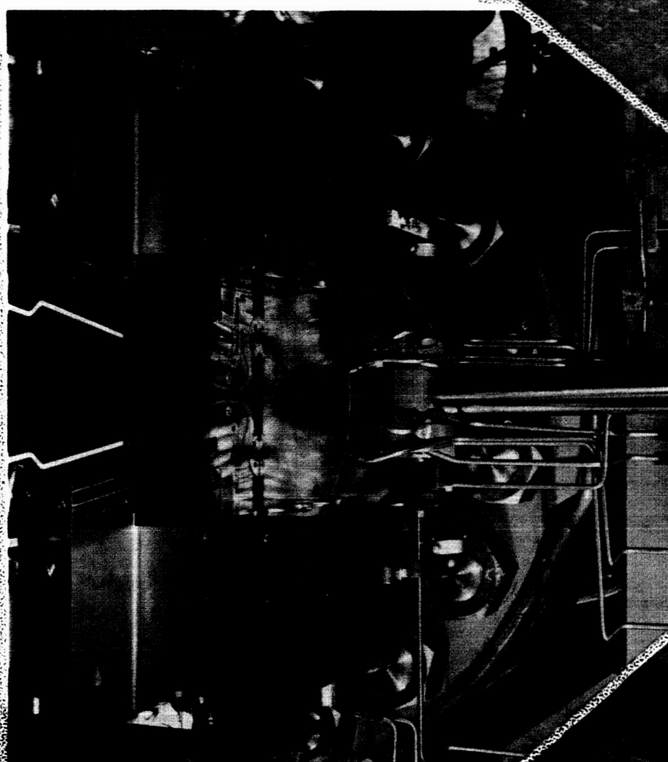


Fig. A-1. 20-in. supersonic wind tunnel

Console area



Throat area



Nozzle and test section

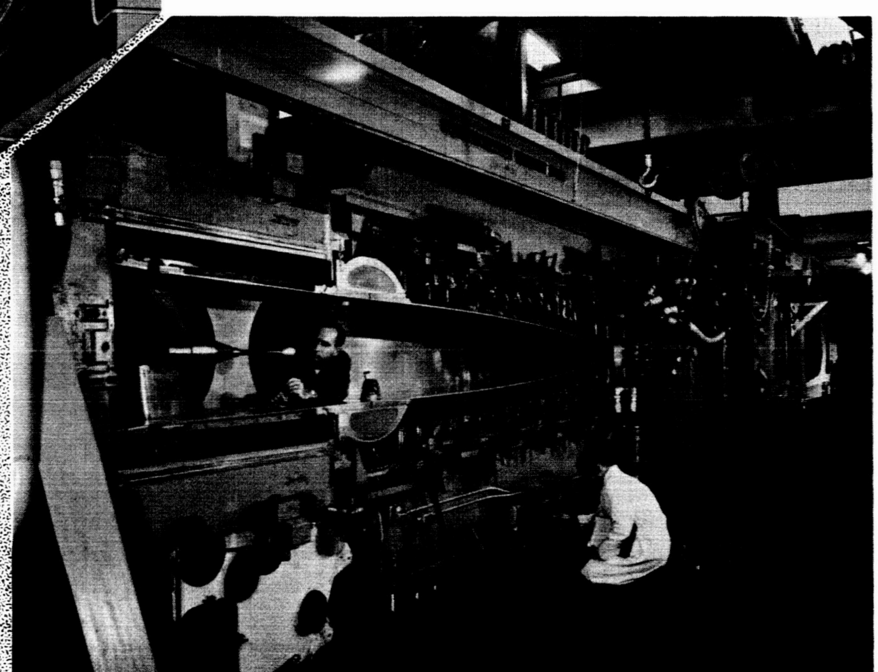
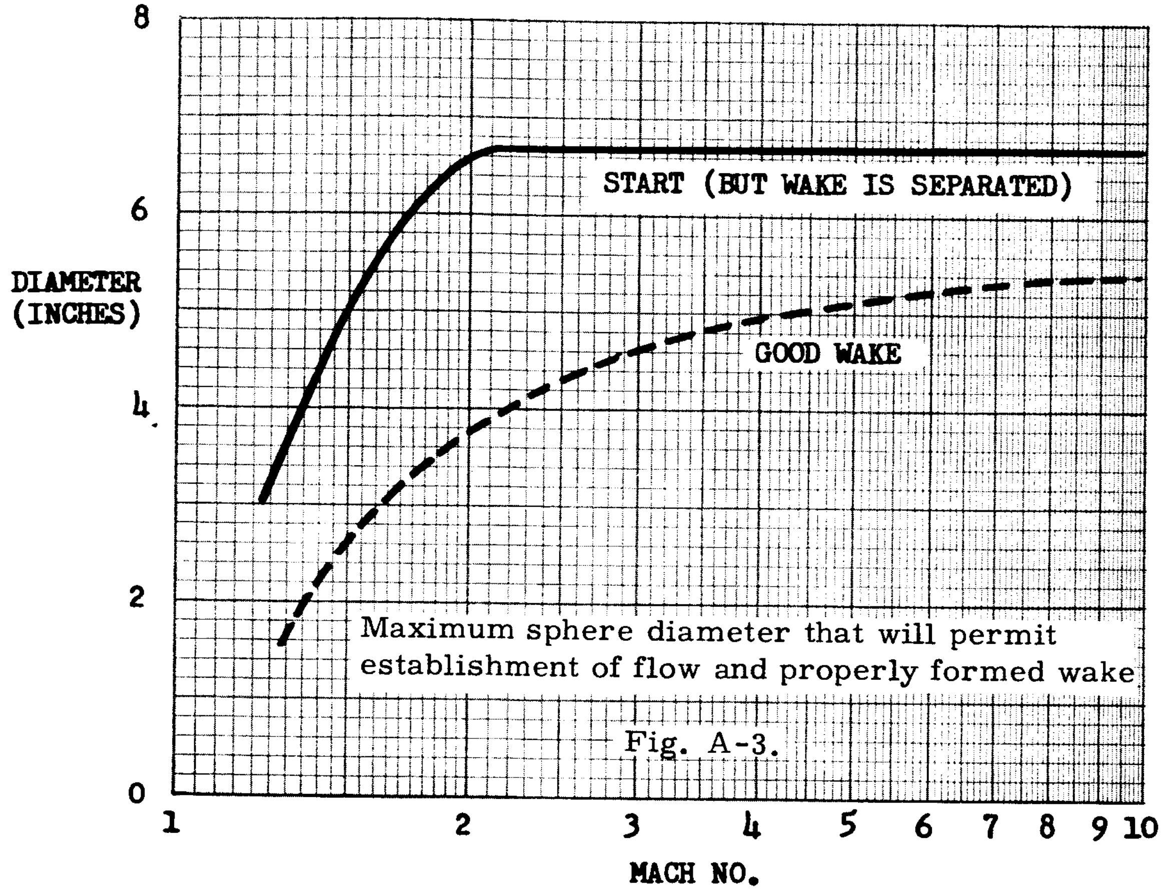


Fig. A-2. 21-in. hypersonic wind tunnel



Maximum sphere diameter that will permit establishment of flow and properly formed wake

Fig. A-3.

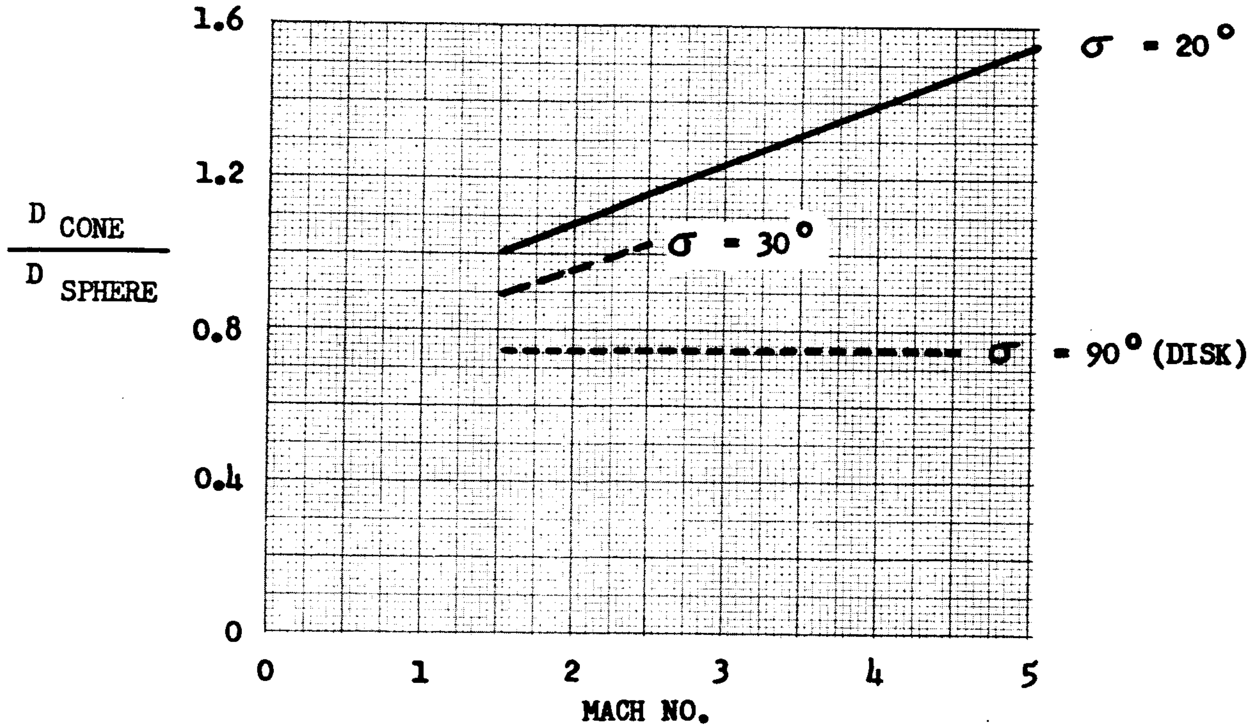


Fig. A-4. Ratio of maximum diameter of cones to maximum diameter of spheres for which both models will just allow establishment of flow in SWT

Tunnel	M	h_g (in.)	w_g (in.)	δ (in.)	δ^* (in.)
SWT	1.4	20	18	0.93	0.17
↓	2	↓	↓	1.15	0.25
↓	3	↓	↓	1.58	0.48
↓	4	↓	↓	1.99	0.77
↓	5	↓	↓	2.51	1.13
HWT	4.1	15.8	19.8	"2.85"	"1.05"
↓	5	18.9	↓	3.00	"1.25"
↓	6	19.5	↓	3.38	1.45
↓	7.25	20.0	↓	3.37	1.58
↓	8.5	20.8	↓	3.85	1.95
↓	9.5	21.1	↓	4.34	2.09
↓	10.1	23.8	↓	"4.75"	"2.37"

h_g Geometric height at the station of the center of the test-section window

w_g Geometric width at the station of the center of the test-section window

δ Total boundary layer thickness

δ^* Boundary layer displacement thickness

(for δ and δ^*:) At 80% of max supply pressure, normal supply temperature

"( )" Estimated values. All other values are measured quantities

Pertinent Test-Section Dimensional Quantities

Figure A-5

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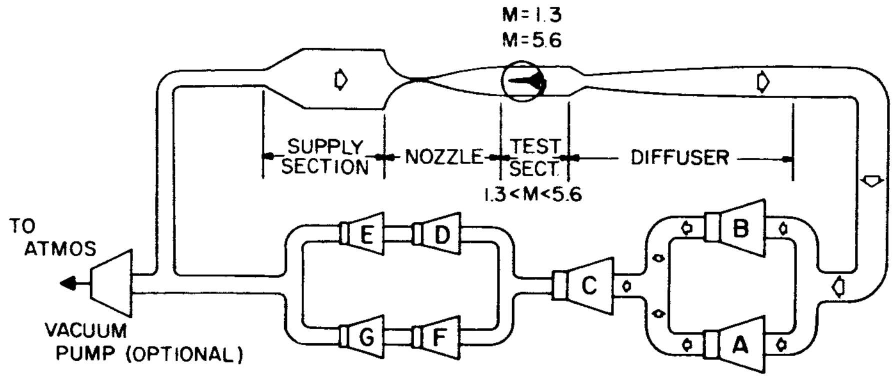
B. OPERATING CONDITIONS

Air is supplied to both tunnels by a compressor plant which contains eleven centrifugal compressors arranged as shown in the simplified schematic drawings in Fig. B-1. Compressors A and B can be connected to compressor L to form a five-stage HWT plant when compression ratio requirements are beyond the capability of the four stage plant ($M > 9.5$). The electric heater is required in the HWT circuit to supply sufficient heat to the supply air so that air condensation does not occur in the test section. The HWT aftercooler cools the heated, low-pressure, tunnel exhaust air to about 100°F in order to eliminate compressor and piping problems inherent in compressing hot air.

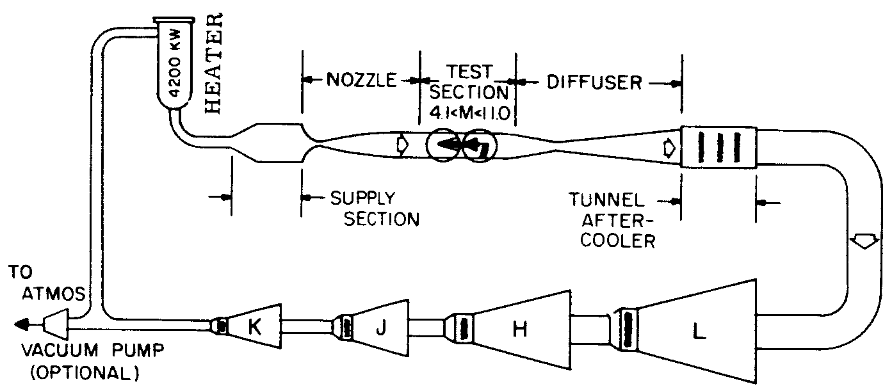
The operating conditions of the JPL wind tunnels are shown in Fig. B-2 to B-7. The conditions enclosed by solid lines have already been verified while those enclosed by dashed lines have not as yet been substantiated. The dashed-line conditions are conservative estimates of conditions which are achievable. Documentation of operating conditions is a continuing project which could be accelerated should a specific need arise. A pump-down compressor can be connected to either wind tunnel for providing supply pressures below atmospheric pressure at $M < 8$.

The minimum supply pressures available in each wind tunnel are dependent upon model and support system geometries. The minimum supply pressure decreases as the test section configuration becomes "cleaner." The minimum operating conditions indicated are for very clean test-section configurations.



COMPRESSOR UNIT	INLET CAPACITY CFM	COMP. RATIO	DESIGN MAX. PRESS. PSIA	MOTOR HP
A, B, C	57,000 each	2.5:1	36	4,000 each
D, F	14,000 each	2.1:1	33	1,000 each
E, G	8,000 each	2.1:1	70	1,000 each

Four stage compressor arrangement for the 20-in. SWT



COMPRESSOR UNIT	INLET CAPACITY CFM	COMP. RATIO	DESIGN MAX. PRESS. PSIA	MOTOR HP
L	82,000	3.8:1	18	4,000
H	22,000	10.0:1	85	3,000
J	3,500	3.4:1	275	2,000
K	1,075	2.7:1	715	2,000

Four-stage compressor arrangement for the 21-in. HWT

Fig. B-1. Wind tunnel compressor arrangements

Operating conditions outside the indicated limits are not necessarily prohibited or impossible. Special consideration will be given to any requests of this nature. As an example the SWT has been run at $M = 0.7$ with small models at low angles of attack, yielding data comparable to tests run in tunnels specifically designed for such test conditions.

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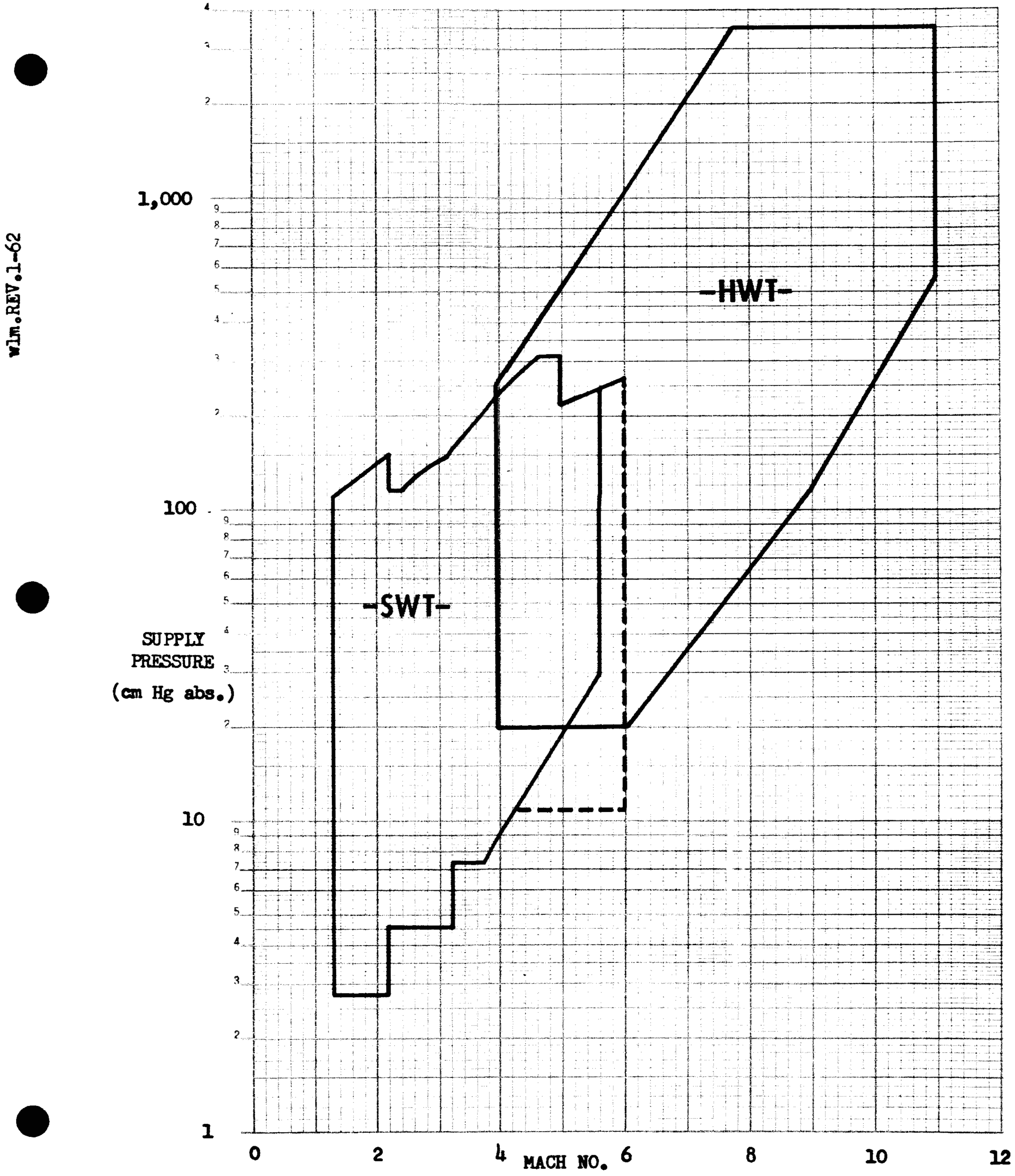

Fig. B-2. Available supply pressures and Mach number range JPL wind tunnels

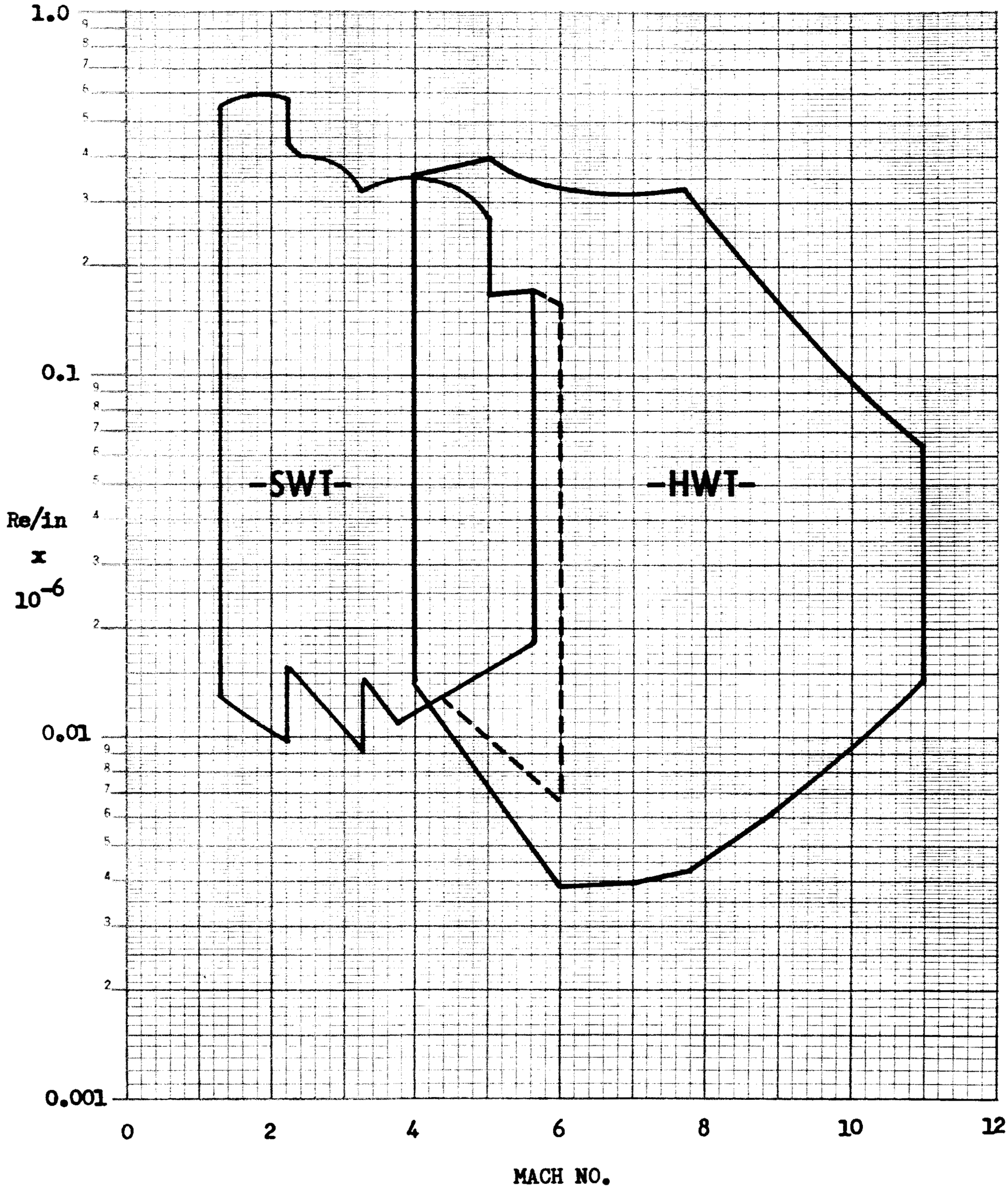

Fig. B-3. Test section Reynolds number per inch vs Mach number JPL wind tunnels

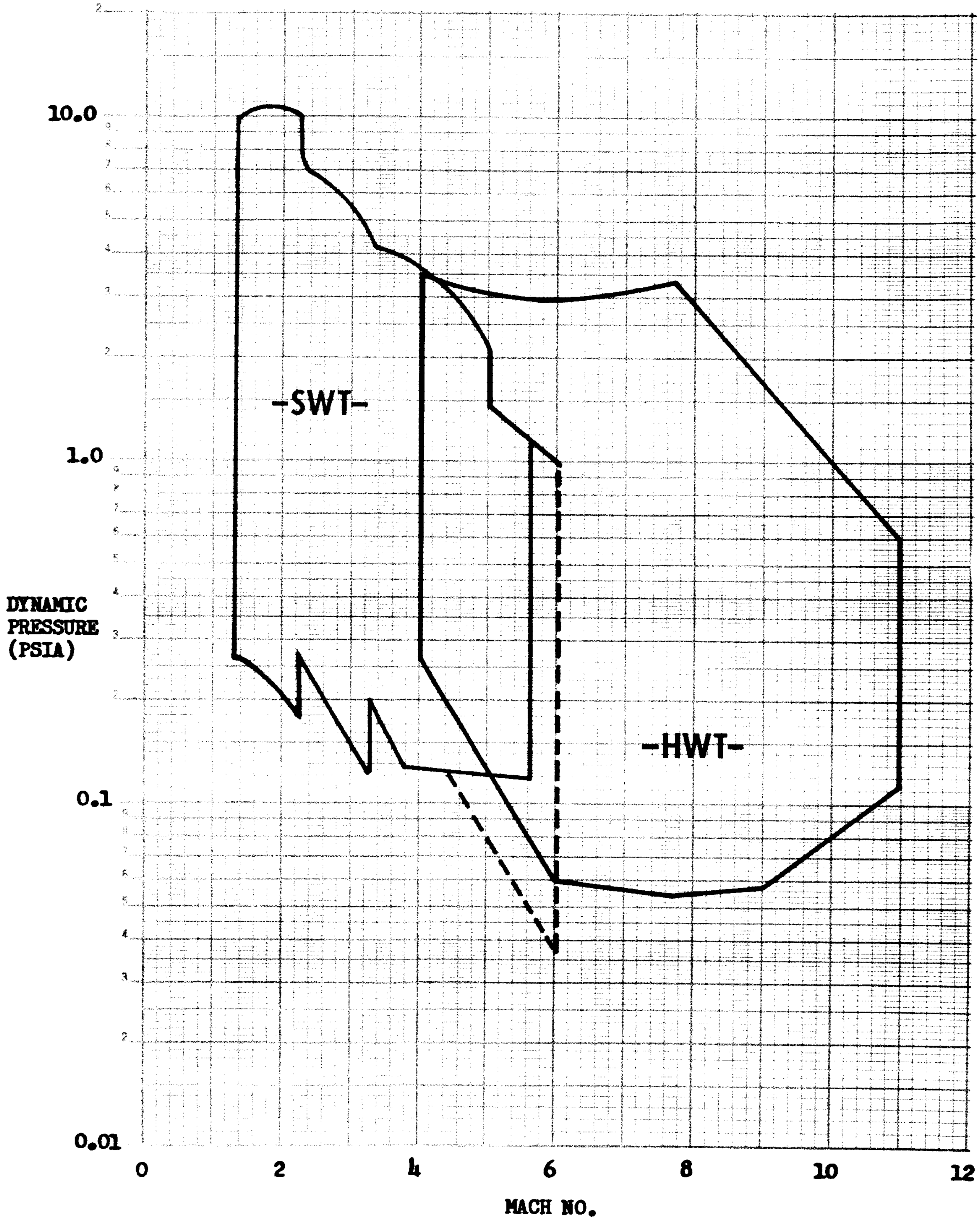

Fig. B-4. Test section dynamic pressure vs Mach number
JPL wind tunnels

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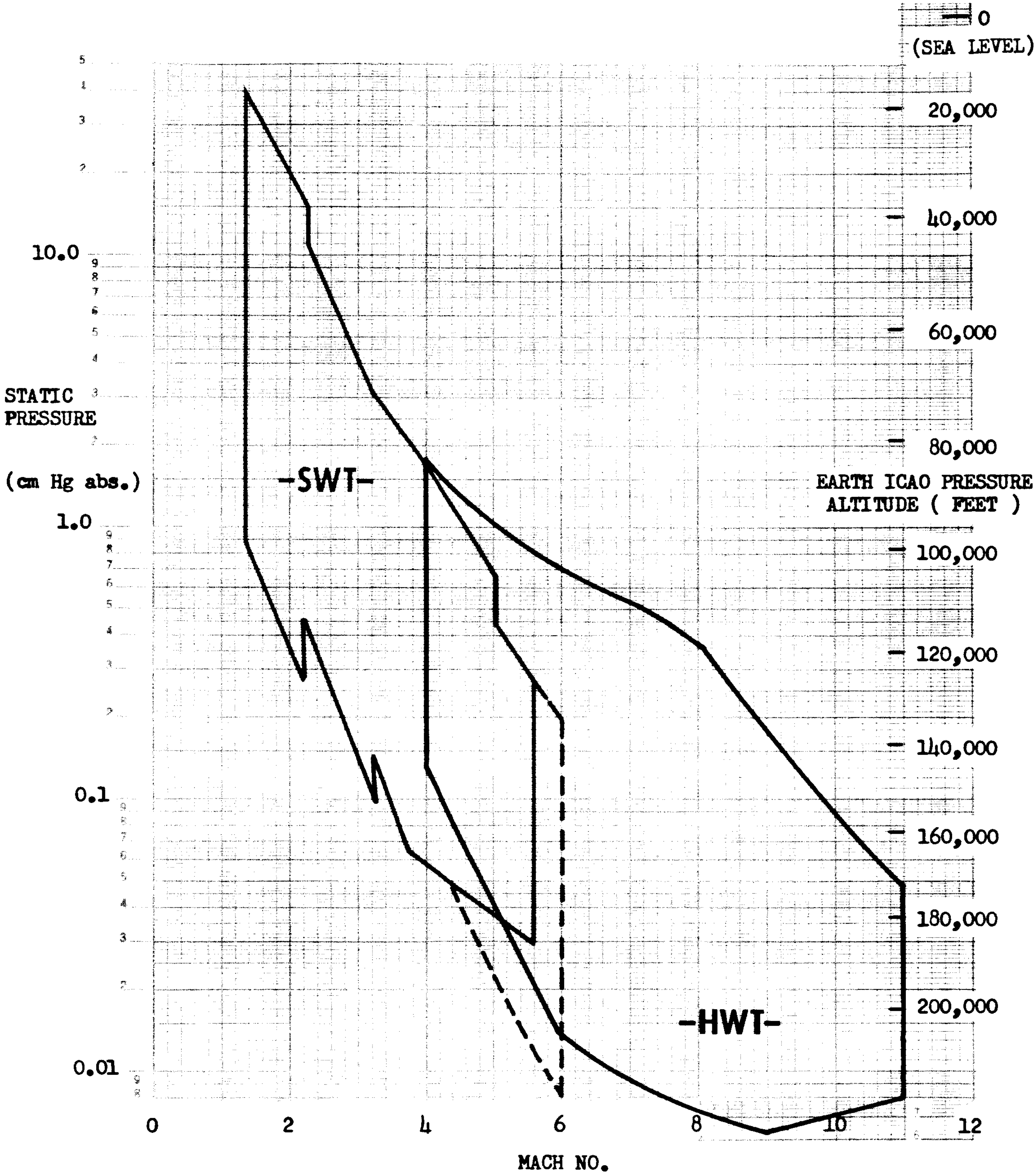

Fig. B-5. Test section static pressure vs Mach number JPL wind tunnels

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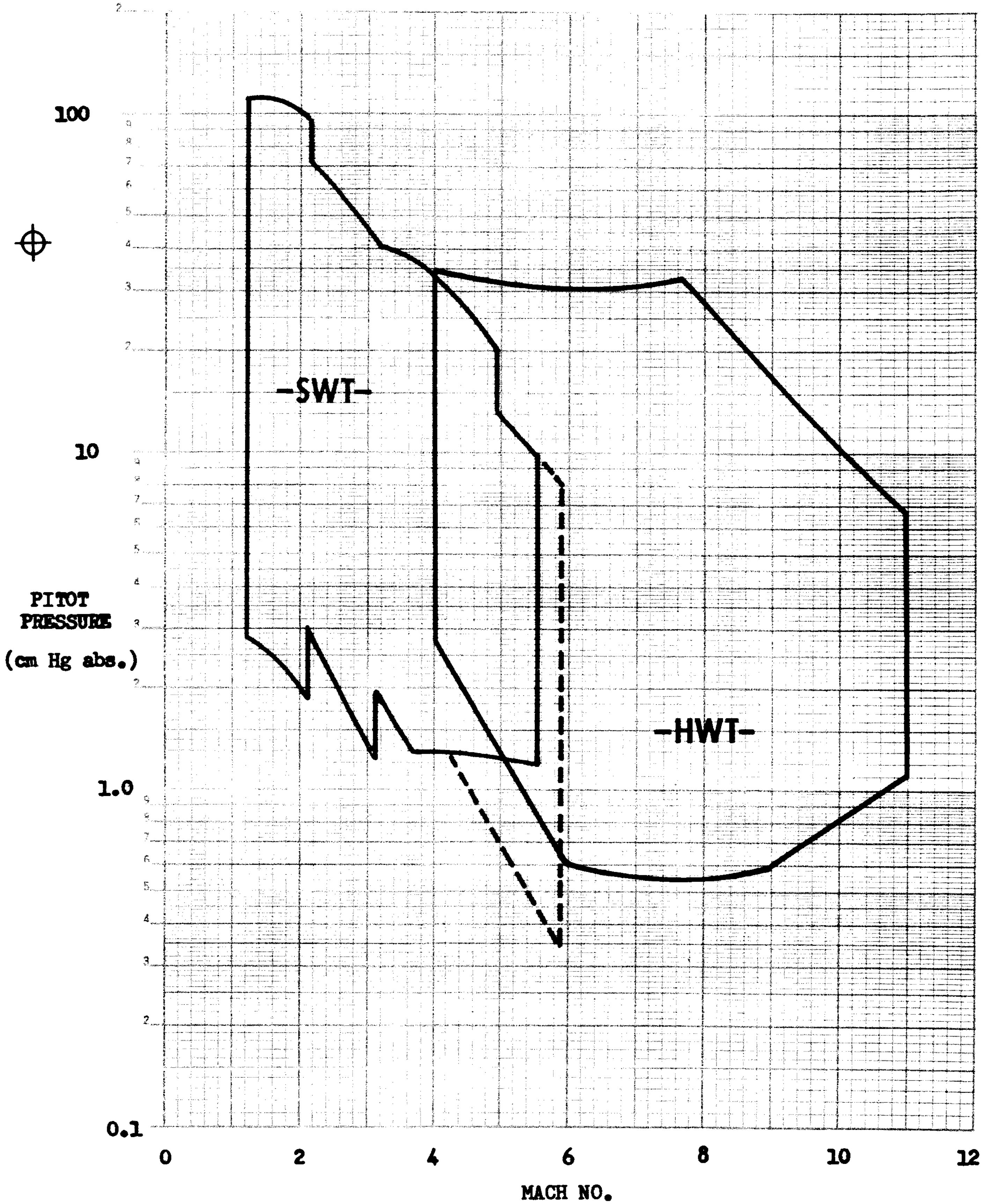

Fig. B-6. Test section pitot pressure vs Mach number
JPL wind tunnels

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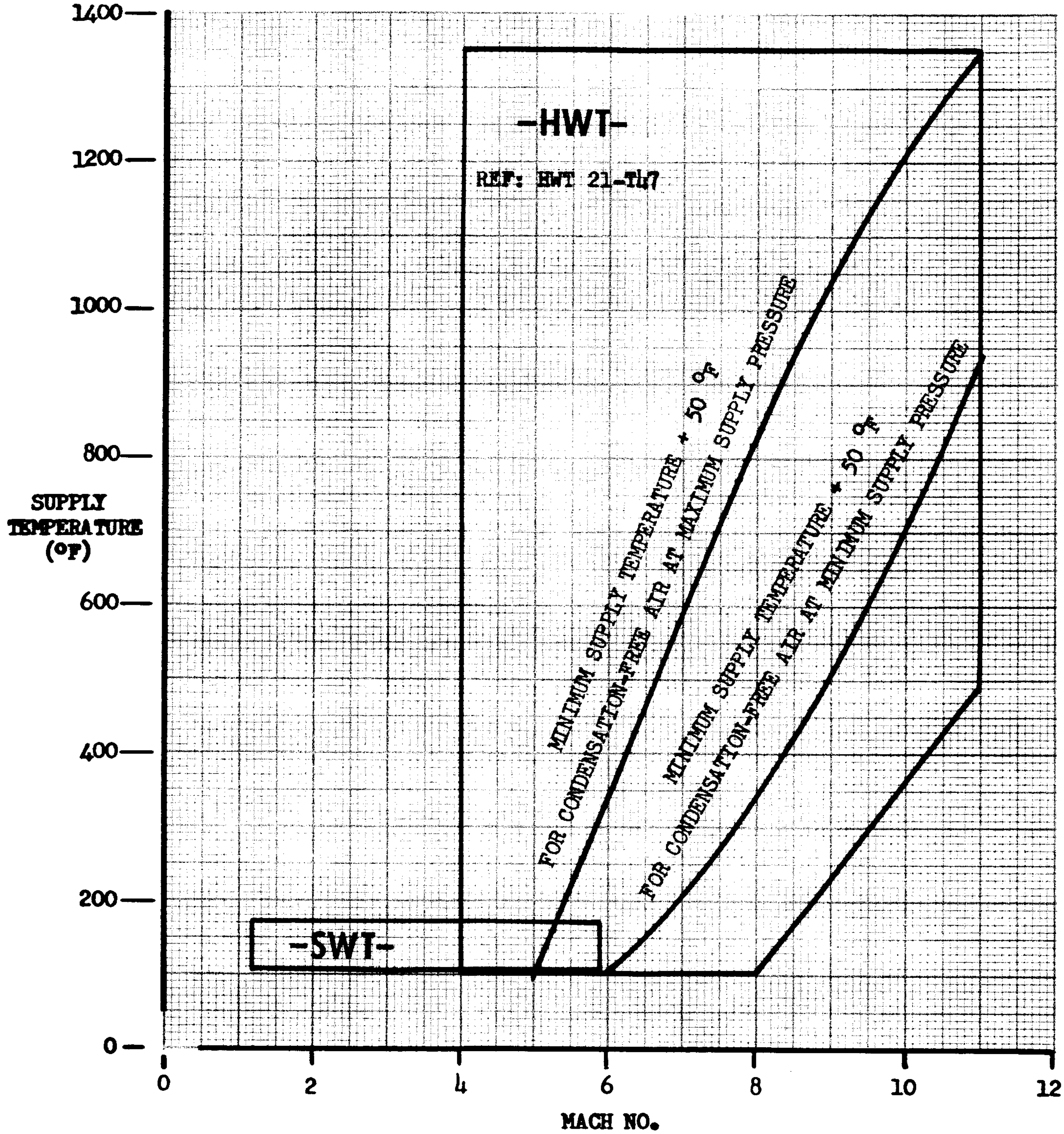

Fig. B-7. Available supply temperature vs Mach number JPL wind tunnels

C. NOZZLE CALIBRATION

The Mach-number distribution on the axial centerline of each tunnel is shown in Fig. C-1 through C-3. The twenty-eight Mach numbers that are represented are those for which the flow has also been satisfactorily inspected three and six inches above, below, and to both sides of the centerline as illustrated in Fig. C-4 for $M = 2.61$ in the SWT. Significant insight into typical flow quality above and below the centerline can be gained from Fig. C-5 which shows the vertical Mach number (pitot-pressure) profiles for several nominal Mach numbers in each tunnel. The total-temperature profiles for several Mach numbers in the HWT are shown in Fig. C-6. As noted in Sect. A the pitot-pressure and total-temperature cores are essentially the same at any given Mach number in the 20-in. SWT.

Since the tunnel supply conditions have a significant effect on the boundary layer on the walls of the HWT, Fig. C-7 and C-8 have been included to illustrate the effects of supply pressure and temperature on the Mach-number distribution in this tunnel.

One of the unique attributes possessed by an adjustable, flexible-plate nozzle is its ability to provide any desired test-section Mach number that is mechanically feasible. While a generous number of nozzle shapes have been thoroughly calibrated, the possibility of running with a new or uncalibrated nozzle shape is always present. It has been demonstrated in the case of the SWT and HWT that there is no problem in obtaining good flow with a new nozzle shape. Figures C-9 and C-10 show the initial and final flow quality for two

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Mach numbers in the HWT. "Initial" in this case refers to a calculated* nozzle shape that has been readily installed and run without any experimental corrections. "Final" refers to the accepted operational shape that has been experimentally optimized to provide the best possible flow in the test section. Obviously if calibration time were unlimited, slightly better flow could be obtained for most nozzles. It should be noted that the regular waviness in the centerline Mach-number distribution results from scalloping of the flexible plates between jacks. The amplitude of this effect is controlled by the plate thickness, jack spacing, and pressure difference across the plate, and therefore this effect cannot be eliminated by changing the nozzle shape.

When an "uncalibrated" nozzle shape is run in either tunnel, the pitot-pressure and hence the Mach number is always determined at an axial station just upstream of the model. In the HWT it is possible to make two nearly vertical pitot-pressure surveys simultaneously just upstream of the model. The profiles are in vertical planes located 3 in. to either side of the centerline. Two probes were chosen to increase the amount of flow that could be inspected and to permit straddling the tip of a long model. A diagonal trace such as shown in Fig. C-11 is made several times a day in the HWT in order to inspect the nozzle air flow and to determine the test section Mach number whenever the supply conditions are changed. A single probe located 3 in. from the centerline performs this function in the SWT. This technique occasionally saves valuable test time by uncovering ordinarily hidden flow problems caused by a seal leak, inconsistencies in the measurement of supply conditions, etc.

*The technique used in designing the JPL nozzle shapes is described in Ref. 2.

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It must be noted that in the HWT, because of limited calibration time, it was necessary to optimize a nozzle shape at near the maximum supply pressure which is where most tests are run. This means that for supply pressures different from this "optimized calibration" pressure the flow will deviate in a smooth manner from the "optimized" flow due to changes in the tunnel boundary layer. Attention is again called to Fig. C-7 for an example of this situation. These deviations become less significant with decreasing Mach number and in fact do not warrant generating additional nozzle shapes as a function of supply conditions.

The flow inclination on the centerline in the two tunnels is felt to be negligible from a practical point of view. In the SWT the flow inclination was measured and found to be ±0.1 deg or less over the Mach-number range. In the HWT the flow inclination is ±0.15° or less for $M < 9$; the flow inclination at $M \geq 9$ is expected to be slightly larger than ±0.15° although this has not yet been verified.

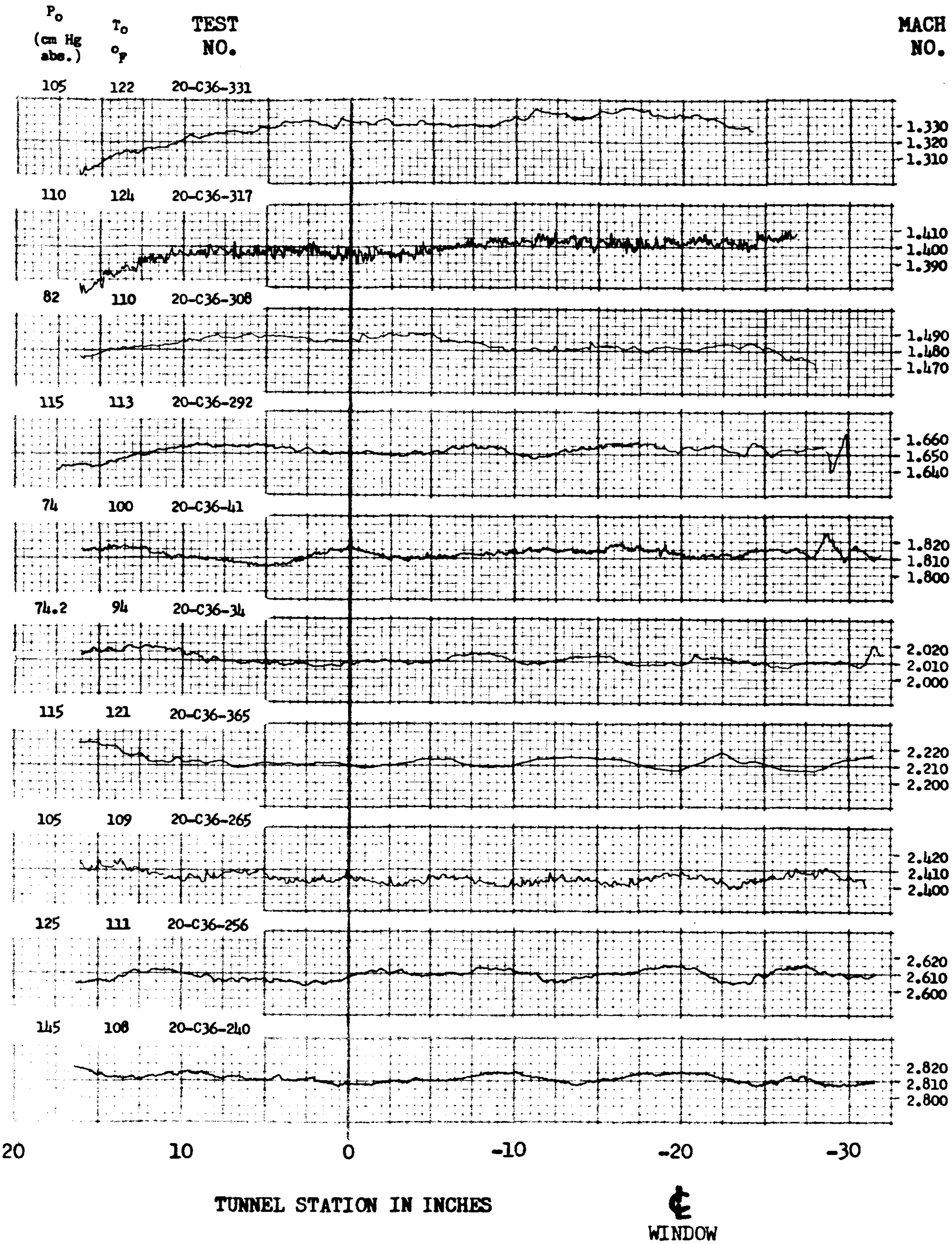

Fig. C-1. Centerline MachNo. distributions in the 20-in. SWT for M = 1.33 to 2.81

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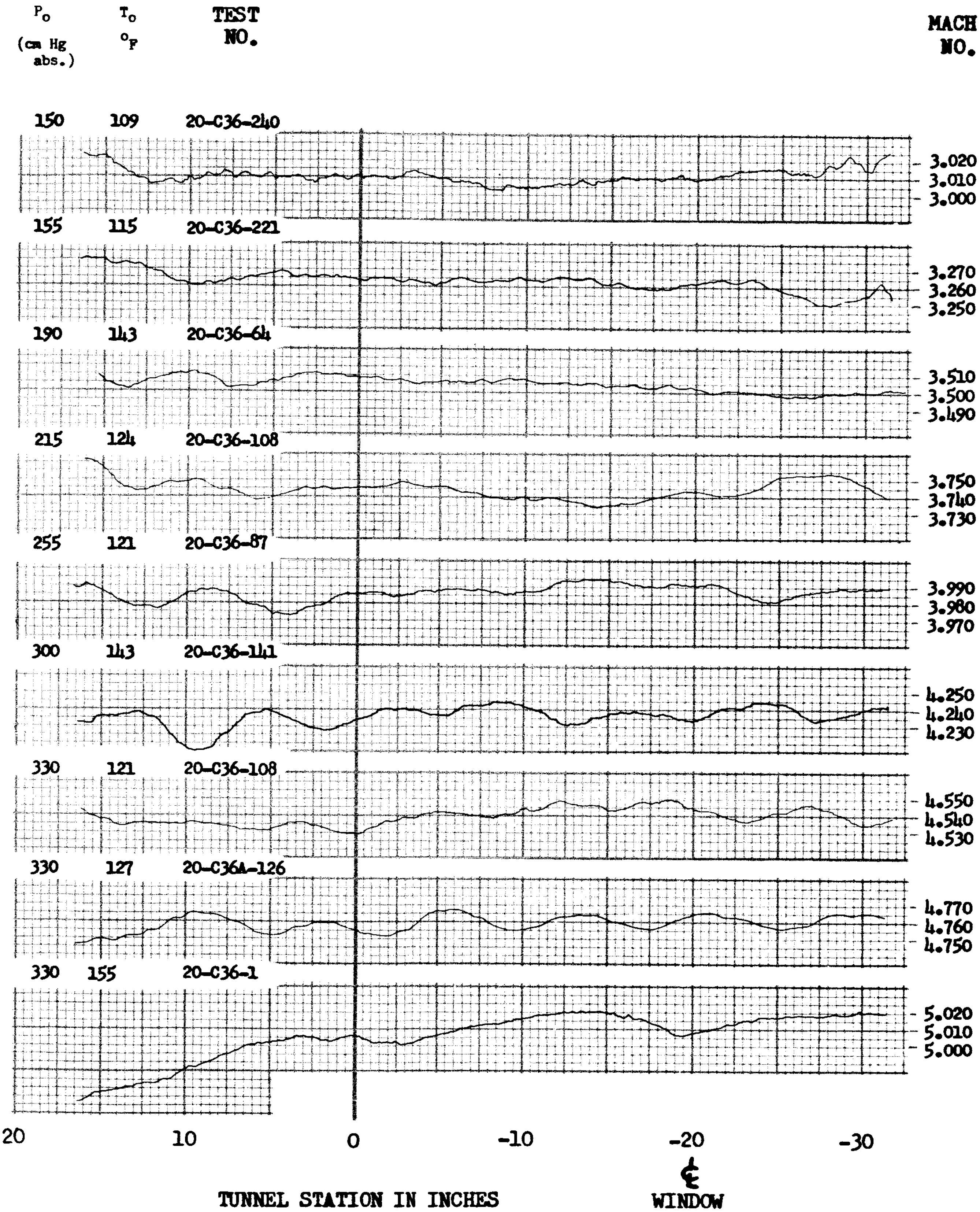

Fig. C-2. Centerline Mach No. Distributions in the 20-in. SWT for M = 3.01 to 5.01

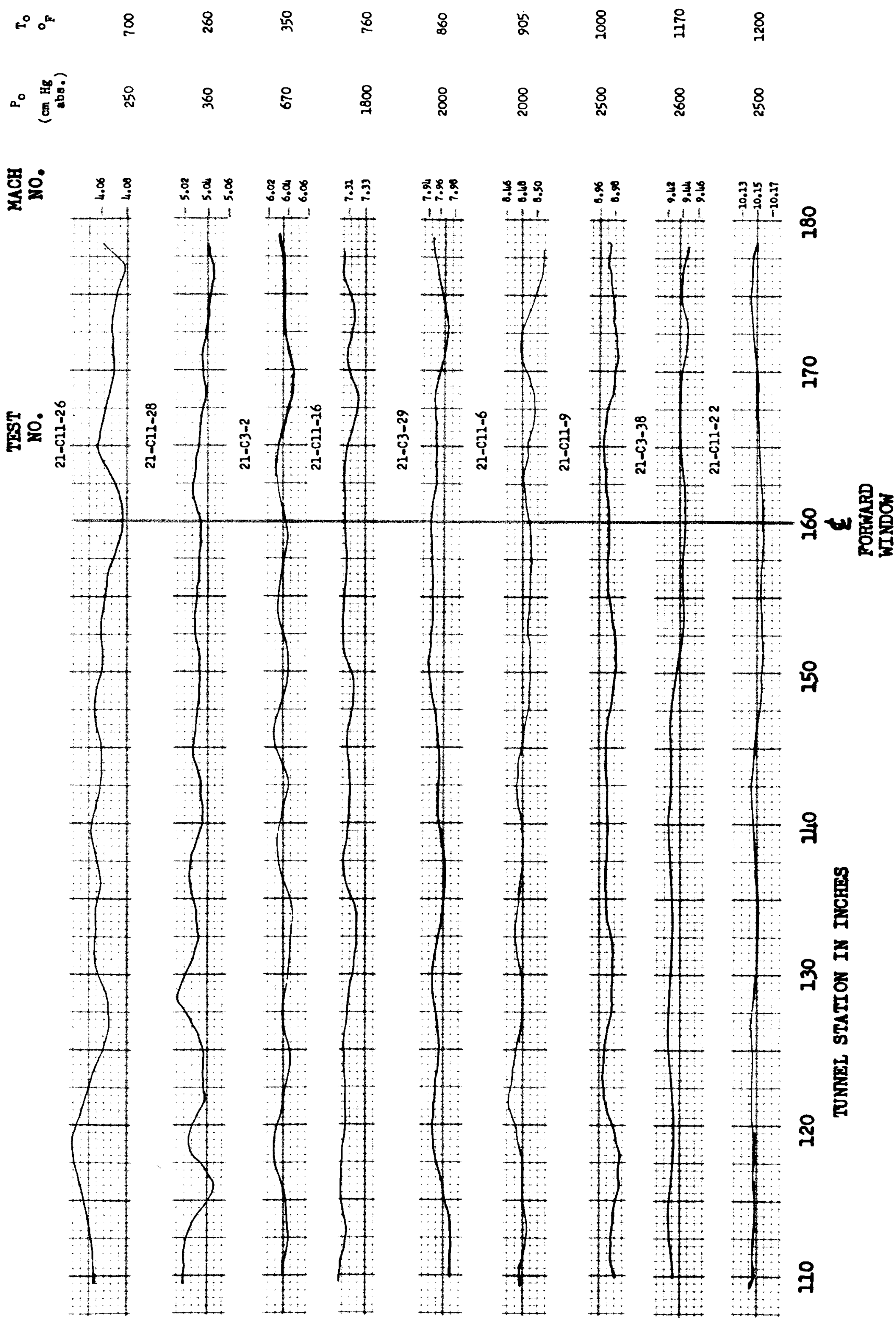

Fig. C-3. Centerline Mach No. distributions in the 21-in. HWT for M = 4.1 to 10.1

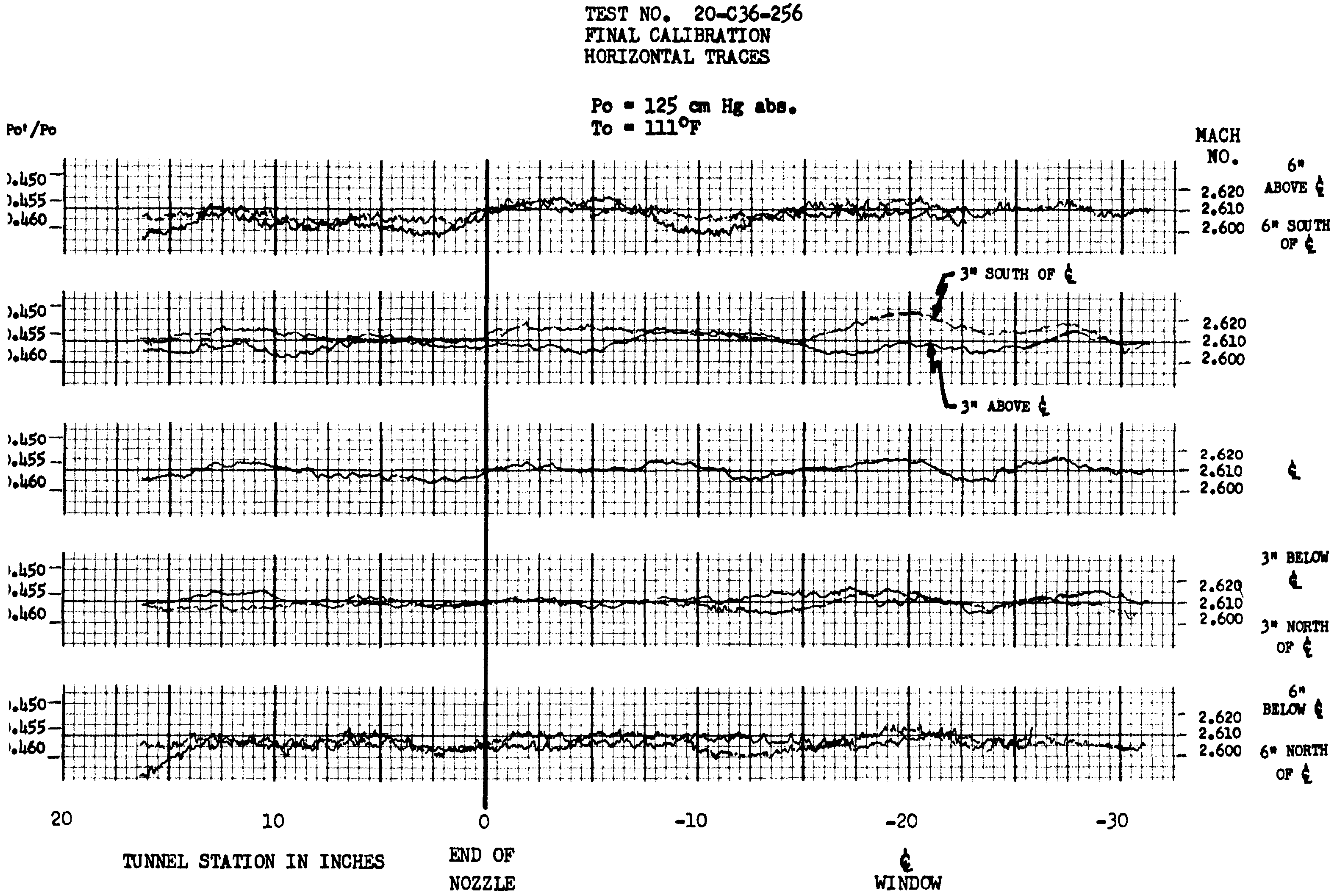

Fig. C-4. Complete Mach No. distributions in the 20-in. SWT for M = 2.61

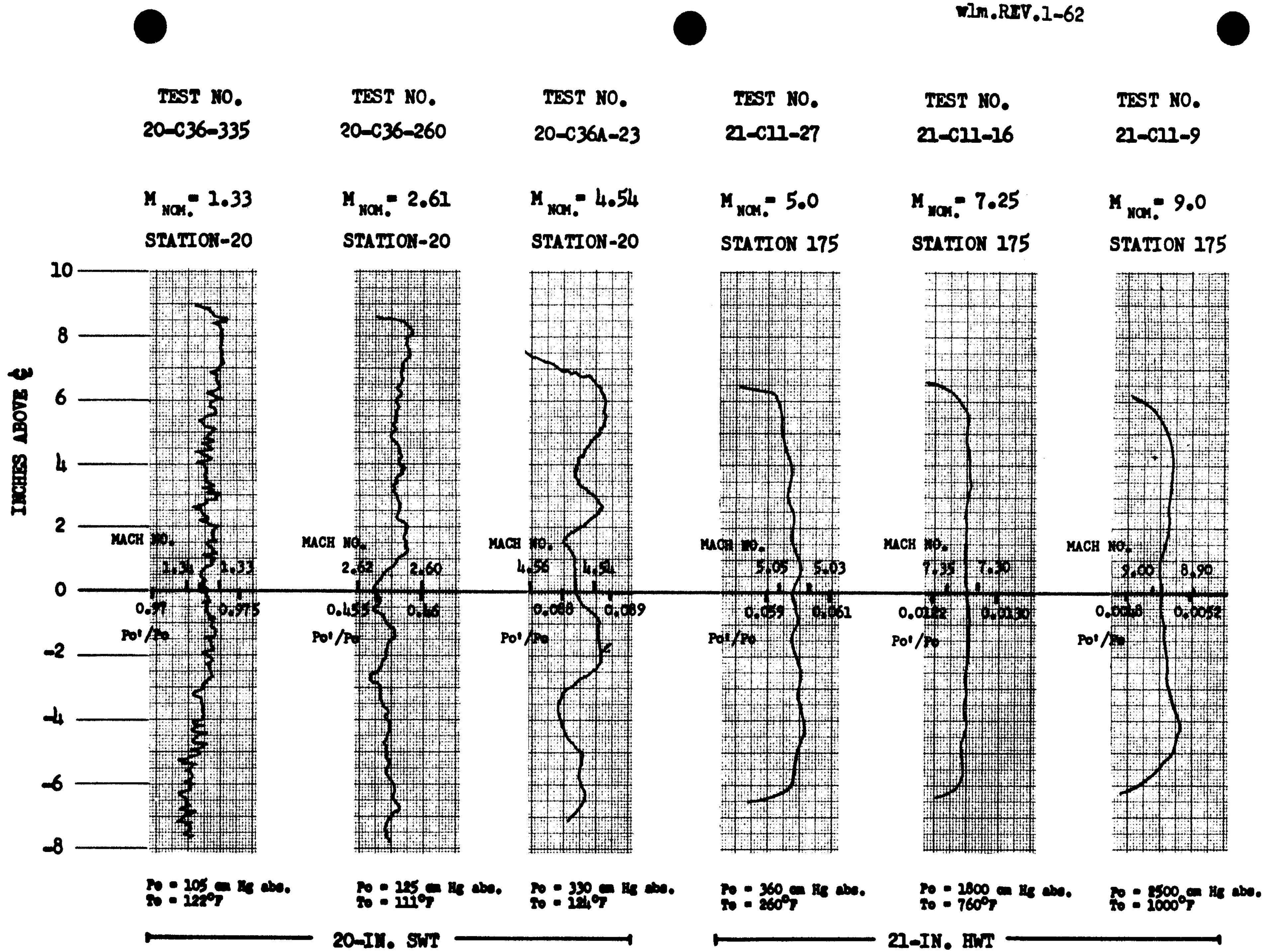

Fig. C-5. Vertical Mach No. distributions in the test sections of the 20-in. SWT and 21-in. HWT

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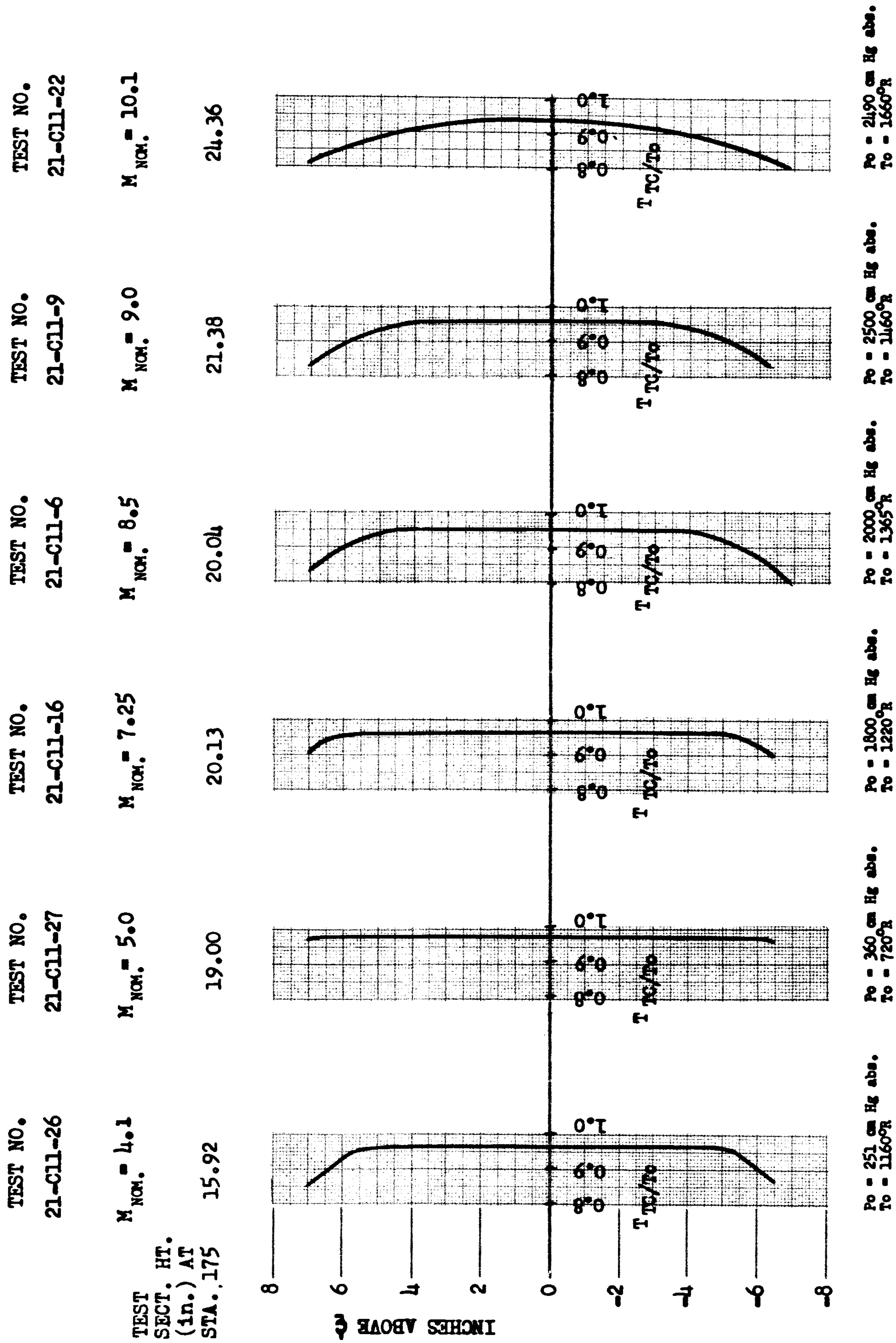


Fig. C-6. Vertical temperature distributions at Station 175 in the test section of the 21-in. HWT

P_o = 1,000 cm Hg abs. T_o = 855°F, Run 24 points 3 and 4
P_o = 507 cm Hg abs. T_o = 843°F, Run 25 points 1 and 3
P_o = 3,180 cm Hg abs. T_o = 920°F, Run 27 points 3 and 4
P_o = 1,930 cm Hg abs. T_o = 890°F, Run 31 points 8 and 9

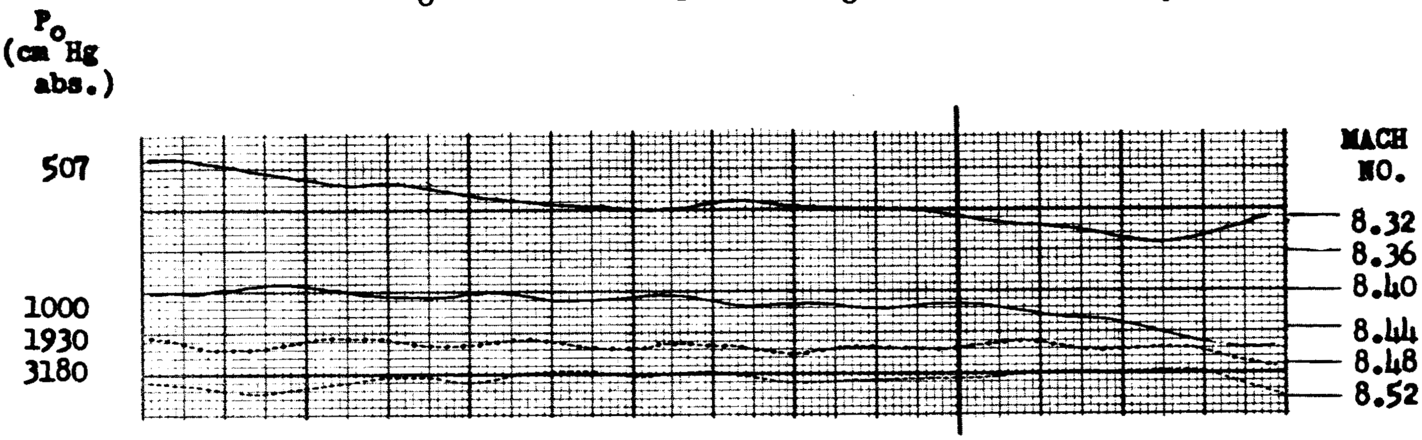


Fig. C-7. Effect of supply pressure on the centerline Mach No. distribution in the M = 8 1/2 nozzle of the 21-in. HWT

P_o = 2,050 cm Hg abs. T_o = 420°F, Run 23 point 2
P_o = 1,975 cm Hg abs. T_o = 500°F, Run 23 point 1
P_o = 1,940 cm Hg abs. T_o = 645°F, Run 23 point 3
P_o = 1,880 cm Hg abs. T_o = 746°F, Run 23 point 4
P_o = 1,930 cm Hg abs. T_o = 890°F, Run 31 points 6 and 7

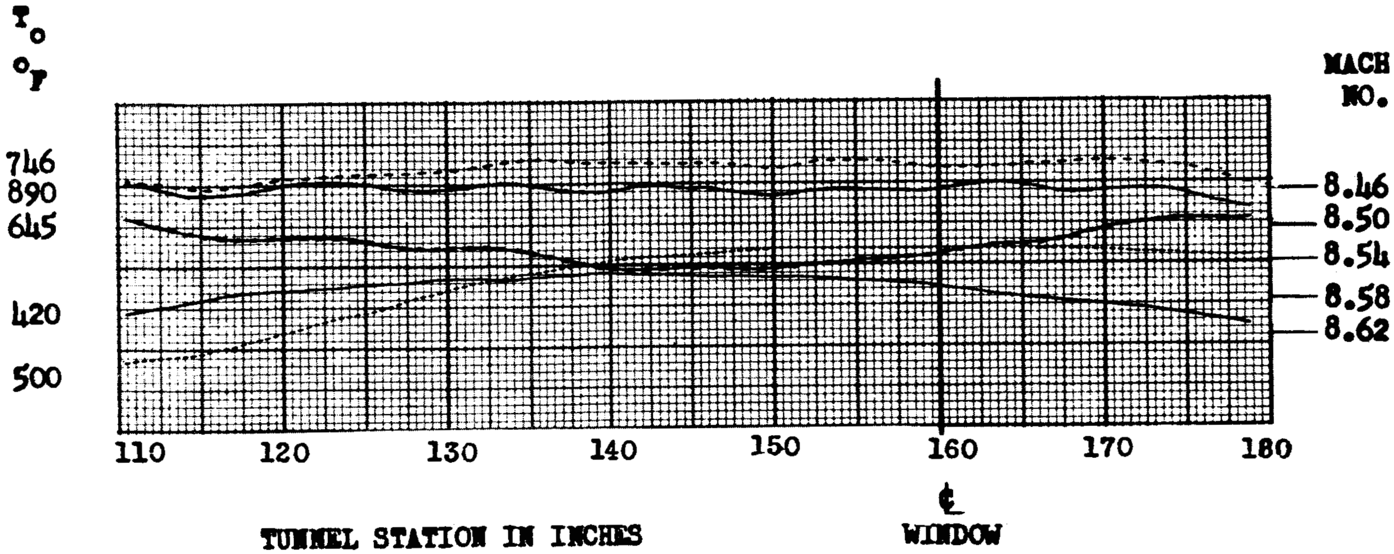
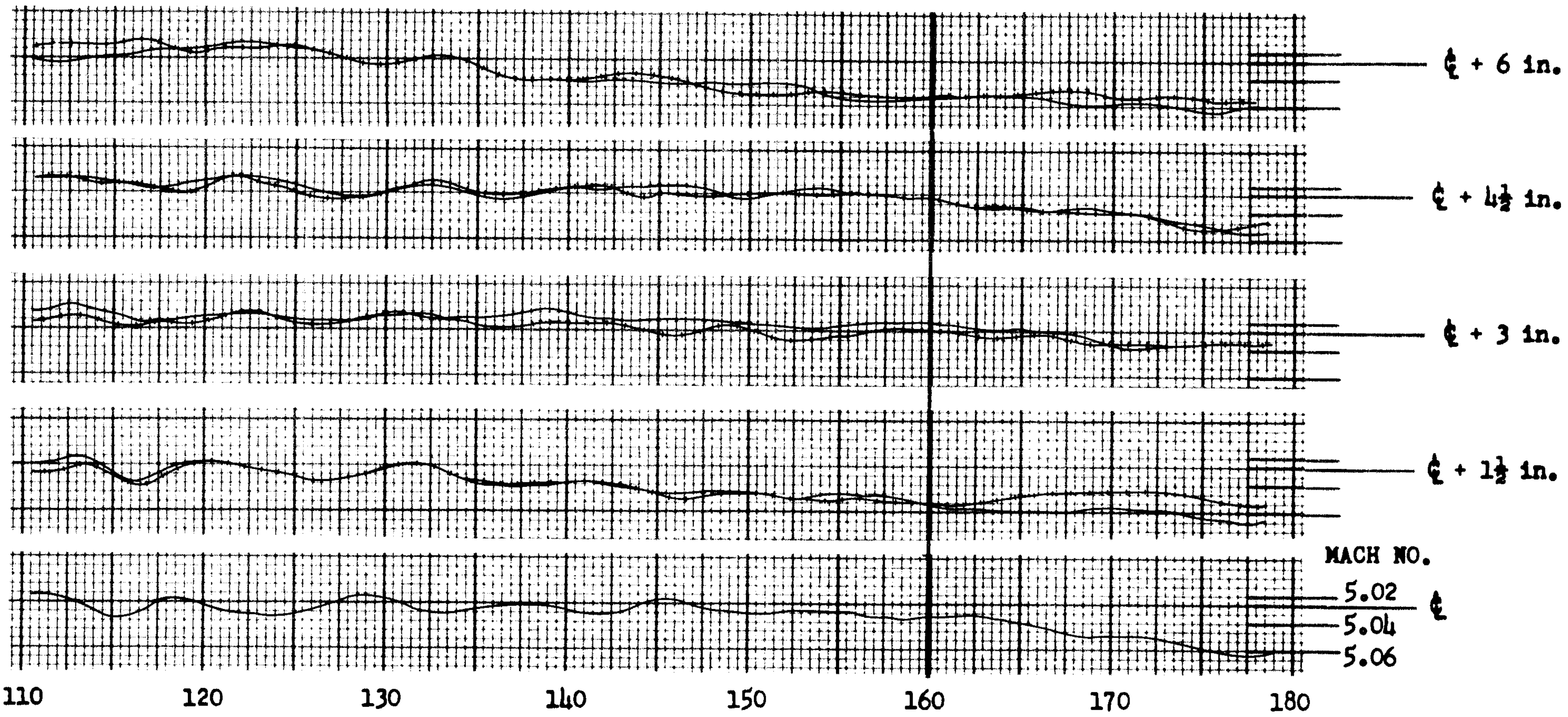


Fig. C-8. Effect of supply temperature on the centerline Mach No. distribution in the M = 8 1/2 nozzle of the 21-in. HWT

P_o = 360 cm Hg abs.
T_o = 250°F

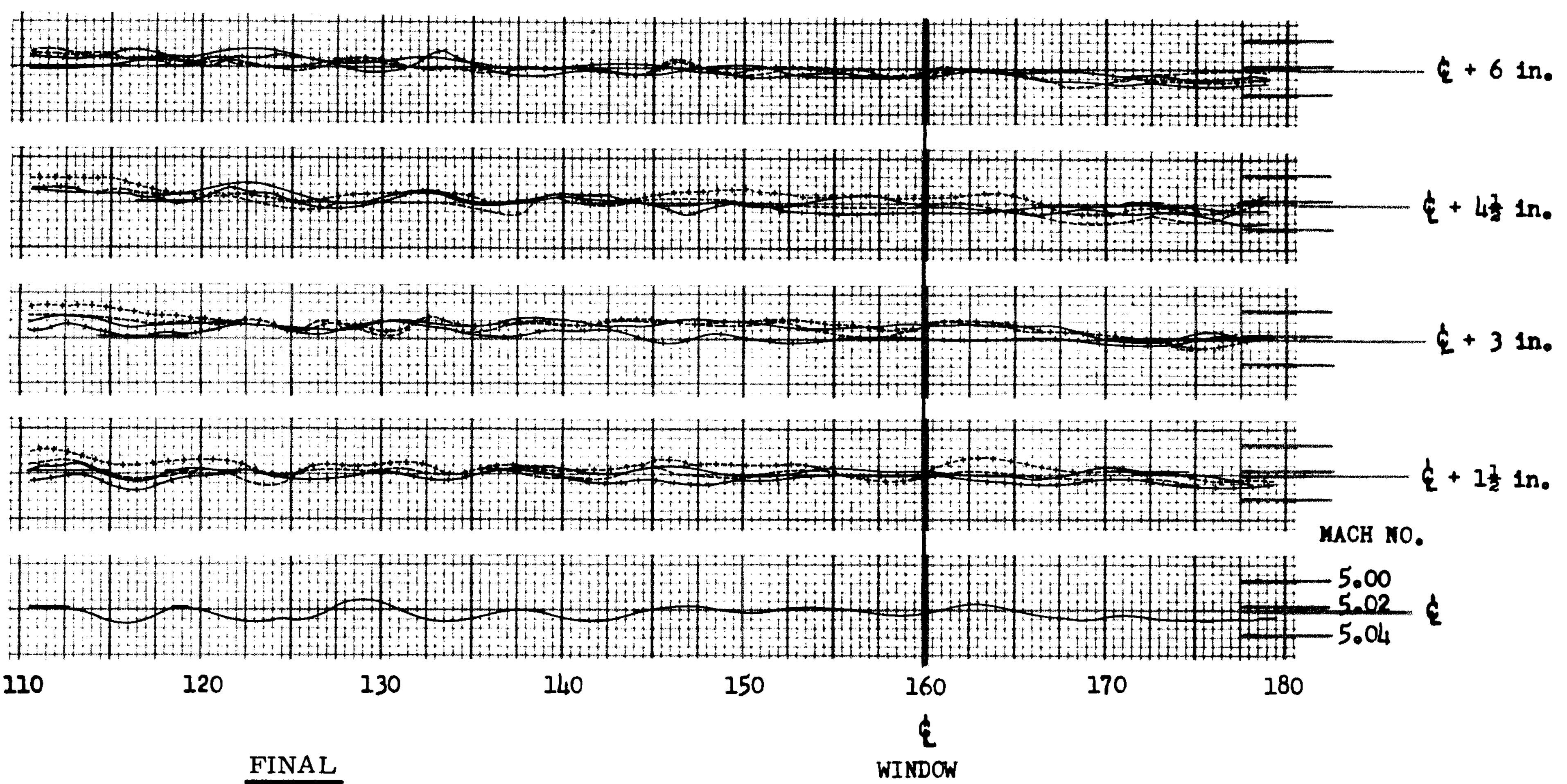
Above ℄, Run 46, points 3 and 4
Below ℄, Run 46, points 1 and 2



INITIAL

P_o = 355 cm Hg abs.
T_o = 260°F

Below ℄, Run 49, points 10 and 11
Above ℄, Run 49, points 12 and 13
West of ℄, Run 49, points 14 and 15
East of ℄, Run 49, points 16 and 17

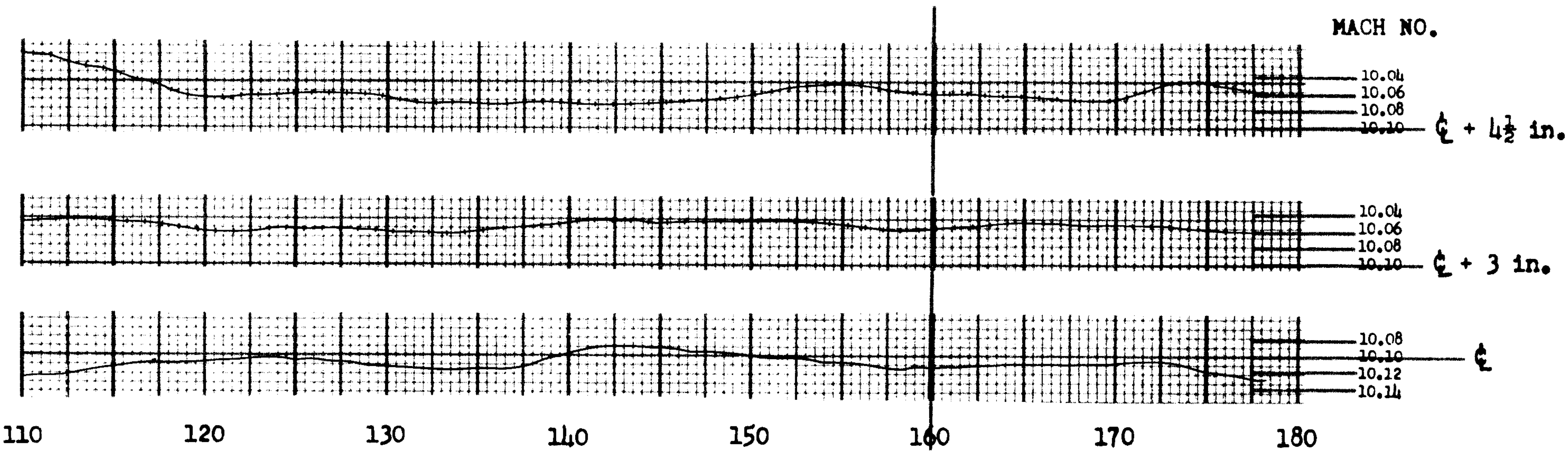


FINAL

Fig. C-9. Comparison of initial and final Mach No. distributions for the 21-in. HWT M = 5 nozzle

P_o = 2500 cm Hg abs.
T_o = 1250°F

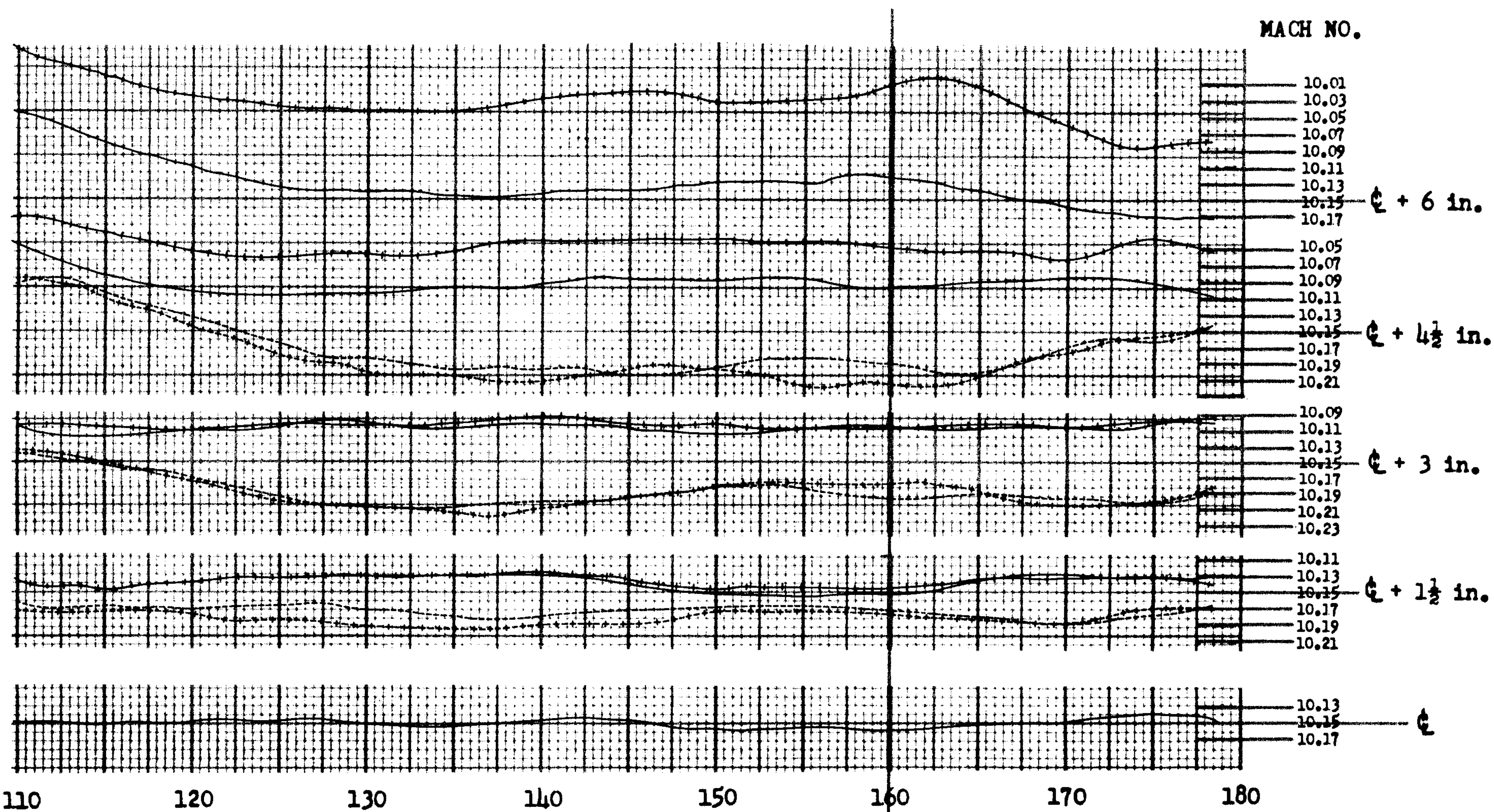
Below ℄, Run 22, point 1



INITIAL

P_o = 2500 cm Hg abs.
T_o = 1200°F

————	Above ℄, Run 22, points 25 and 26
+—+—+	Below ℄, Run 22, points 21 and 22
– – – – –	West of ℄, Run 22, points 23 and 24
+–+–+	East of ℄, Run 22, points 27 and 28



FINAL

℄
WINDOW
TUNNEL STATION IN INCHES

Fig. C-10. Comparison of initial and final Mach No. distributions for the 21-in. HWT M = 10.1 nozzle

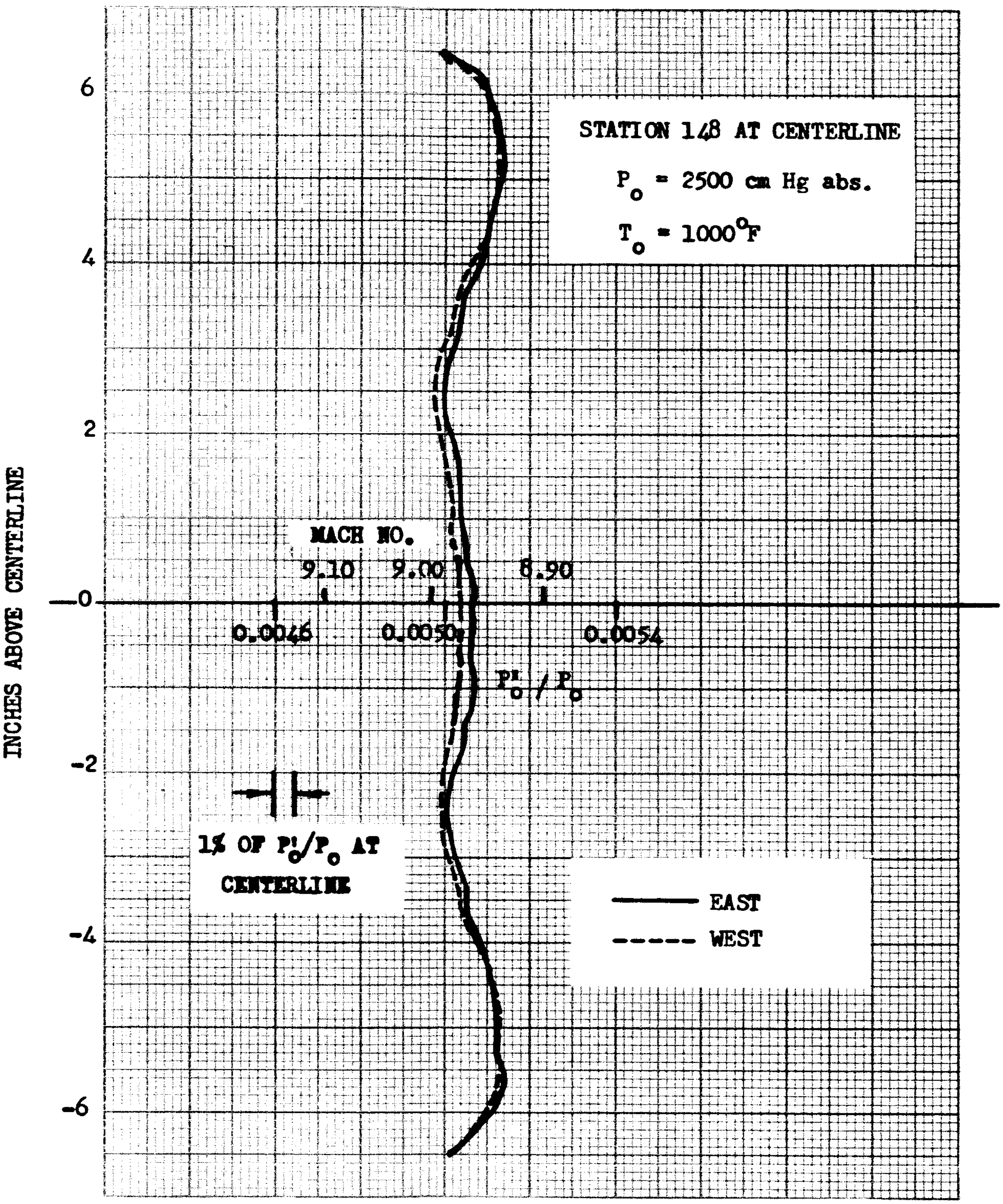


Fig. C-11. Sample diagonal trace at M = 9.0 in the test section of the 21-in. HWT

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D. MODEL SUSPENSION SYSTEMS

Although the basic suspension system equipment for the 20-in. SWT and the 21-in. HWT are similar, there are sufficient differences to warrant separate comments for each tunnel.

I. 20-in. SWT

a. Basic system. The crescent-type support shown in Fig. D-1 can be pitched by remote control from -10 to +20 deg, while its sting socket may be remotely rolled from 0 to 350 deg. The angle-of-attack range can be changed to -1 to +29 deg by placing a 9 deg-bent support between the basic support and the sting which supports the model. It is possible to cover higher 30-deg increments of the angle-of-attack range by fabricating an appropriately bent sting. The rolling range is the same for all angle-of-attack ranges.

b. Windshield mounts. Large-scale models, such as inlets, which are impractical to sting-mount from the basic system can be supported by the windshield which encloses the sector. The angle-of-attack range is -10 to +20 deg.

c. Vertical traverse. A "large" traverse attaches to the test-section ceiling and can traverse the entire test section in the vertical direction while under remote control. Another remotely controlled assembly can be attached to the end of the large vertical traverse, providing 11 in. of axial travel relative to the vertical traverse. A "small" remotely controlled vertical traverse can be attached to the test section in place of the "large" traverse. The vertical travel of the small traverse is limited to about 3 in. relative to any manually-set starting point. The "small" traverse is used mainly for boundary-layer survey work.

d. Sidewall mounts. It is possible to replace one or both of the test-section windows with equipment which permits supporting models from one or both sidewalls. The remotely controlled angle-of-attack range for a model supported from one sidewall is ±27 deg. Models which are attached to both sidewalls cannot be easily pitched by remote control. Flow visualization is possible with sidewall supports although the field of view is limited.

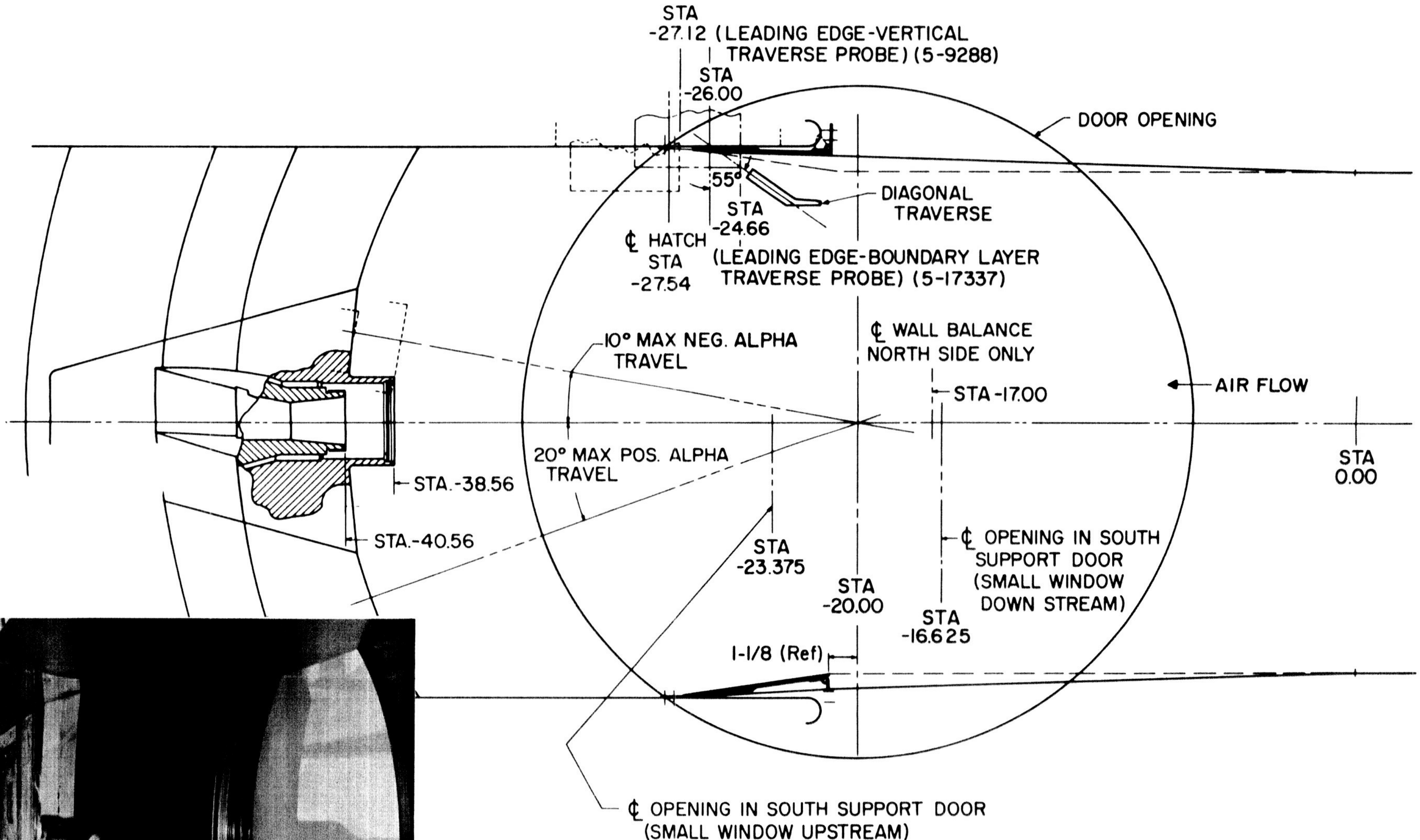
II. 21-in. HWT

a. Basic system. The crescent-type support shown in Fig. D-2 can be pitched by remote control from -10 to +20 deg, while its sting socket may be remotely rolled from 0 to 355 deg. The angle-of-attack range can be changed to -1 to +29 deg by placing a 9 deg-bent support between the basic support and the sting which supports the model. A pitching range of 18 to 48 deg is obtained by using a bent sting with the 9 deg-bent support. It is possible to cover higher 30-deg increments of the angle-of-attack range by fabricating an appropriately bent sting. Whenever the 9-deg bent support is used, the remotely controlled rolling range is -10 to +270 deg.

b. Vertical traverse. The vertical traverse can be installed at any of three axial stations in the ceiling of the test section. The vertical travel of the traverse covers the entire test section and the traverse may also be pitched ±15 deg. It is possible to install the traverse so that its pitching plane is rotated 90 deg from the air flow direction. This installation facilitates making surveys in the wake of a model such as the sphere in Fig. E-2.

III. General Remarks

Special (e.g., wire supports and floor mounts) or new types of model suspension are generated by JPL whenever a persistent or regular need for additional systems becomes evident. However, equipment and stings in particular which may be used only with specific models and then on a limited basis are generally supplied by the contractor. JPL provides drawings and loans taper gages, etc. to ensure satisfactory fits between contractor-made and JPL equipment.



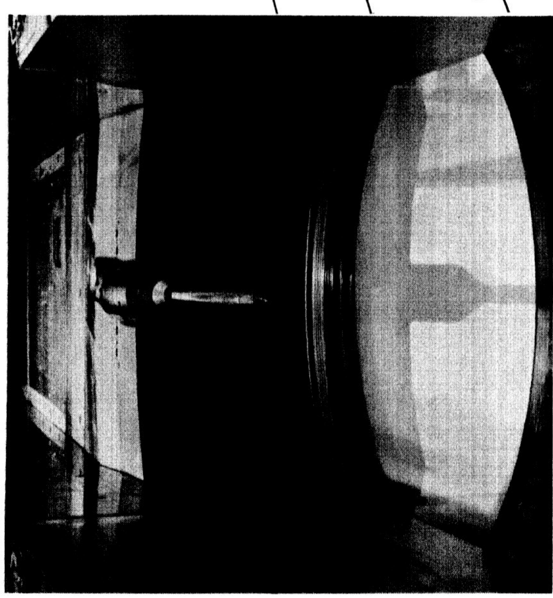


Fig. D-1. 20-in. SWT basic model suspension system

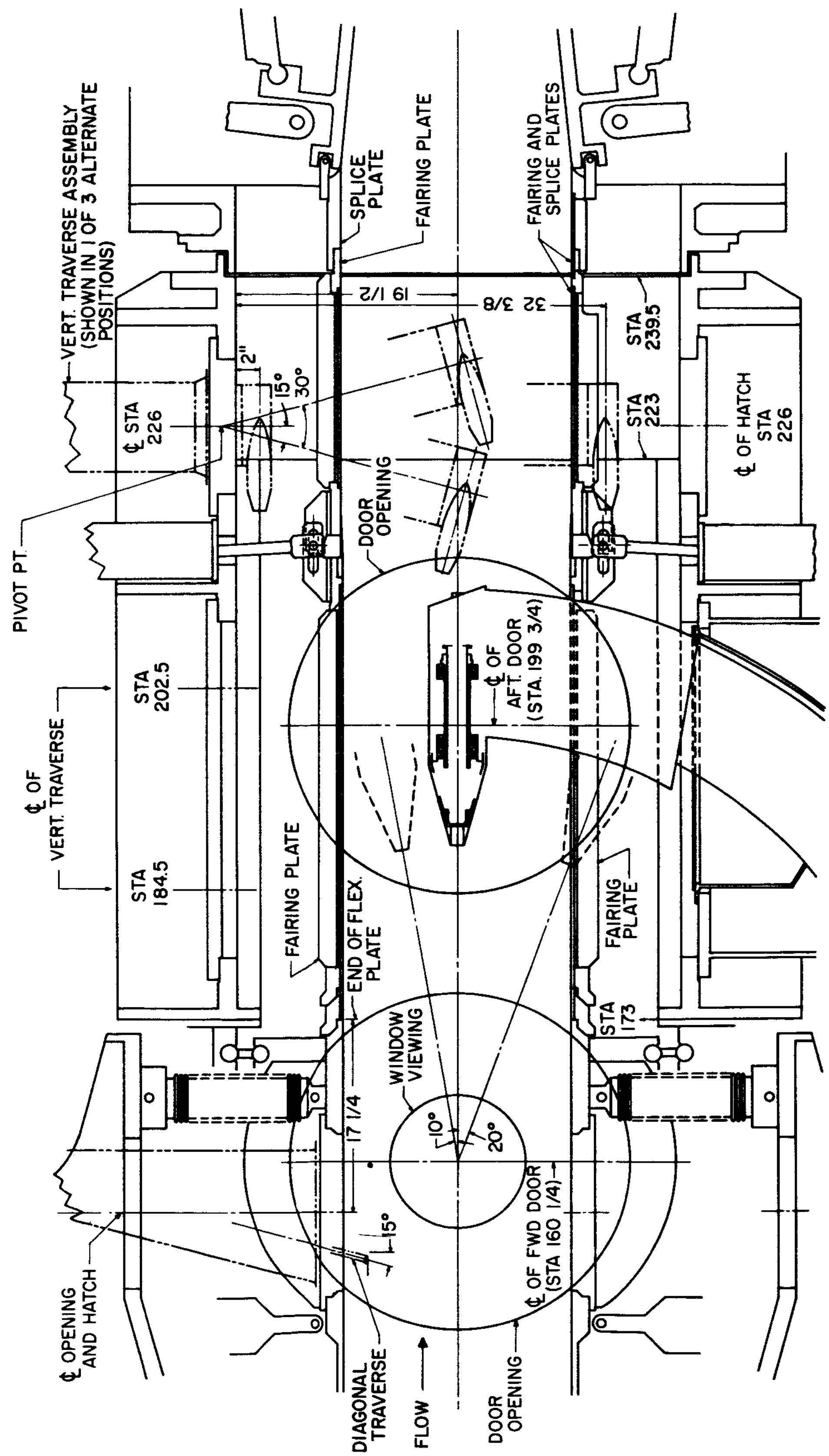


Fig. D-2. 21-in. HWT basic model suspension system

E. TEST INSTRUMENTATION

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There is a variety of instrumentation available for performing tests in the 20-in. SWT and 21-in. HWT. The equipment that is listed below generates a digital, analog, or visual indication of the quantity to be measured, and then this information is collected by data-accumulation equipment which is described in Sect. F of this report. Unless otherwise noted the equipment can be used in either tunnel.

I. Force and Moment Measurements

a. External Balances.

1. Six-component hydraulic balance (fixed part of 20-in. SWT) with high and low ranges extending from −12 to 320 lb of lift and −425 to 3500 in.-lb of pitching moment, for example.
2. 20-in. SWT sidewall balance for determining normal and chord forces and pitching and rolling moments on half-models; a variety of load capacities is available.
3. Single-component special balances.

b. Internal Balances

1. Six-component water-cooled strain gage balances of various capacities ranging from 25 to 200 lb of normal or side force, 15 to 75 lb of chord force and 10 to 30 in.-lb of rolling moment.
2. Five-component (no chord-force data) cooled and uncooled balances with ranges of 40 to 213 lb of normal force and up to 20 in.-lb of rolling moment.

3. One to three-component special balances.

c. Dynamic Stability Equipment

1. Capability in this area is increasing and will be gladly described upon request. An air-bearing support system is available for obtaining damping information with negligible support friction for any angle-of-attack.

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II. Pressure Measurements

a. Model Internal and External Pressure Distributions

1. Multipressure measuring system (MPMS):

   50 and 99 port systems available

   full-scale range = 5, 10, 15, 25, or 50 psia

   resolution = ±0.1% of full-scale

   scanning rate = 6 ports/sec (after reaching equilibrium)

2. Fluid manometry of up to 100 tubes in units of 10; the fluid may be either mercury or silicone oil (sp. gr. ≐ 0.94) in any given 10-tube unit.

3. Special single-point system accurate to ±0.05% of the reading in the range between 5 and 20 mm Hg abs. (the upper limit can be increased, but to what extent is still uncertain; the lower limit can be considerably decreased, but at the expense of absolute accuracy).

b. Pressure Surveying

1. Point-by-point or continuous traces may be made using any one of a number of transducers which are on hand; Moseley plotters

are also available for recording either kind of trace data in a graphic form. The special low-pressure system mentioned in Sect. E-II-a can also be used in point-by-point survey work.

III. Temperature Measurements

a. Model Surface Temperature Distribution

1. Slow-speed scanning system:

   99 channel capacity

   full-scale range = 2.5 to 25+ mv; can be zeroed anywhere within range

   resolution = ±0.1% of full-scale

   scanning rate = 1.5 sec/channel

   common ground (e.g., the model skin) between thermocouples is permissible.

2. High-speed scanning system:

   47 channel capacity

   best full-scale range = ±10 mv

   scanning rate = 0.001 sec/channel

   resolution, zeroing, and common ground comments from item 1 of Sect. E-III-a apply also to the high-speed system

This system is presently used for transient heat transfer testing in the HWT where the model is reduced to an "isothermal" condition by nitrogen exhausted from a remotely controlled cooling shield which is shown in Fig. E-3.

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IV. Flow Visualization

a. Optical Equipment

1. A schlieren system is permanently installed in each tunnel area for use in viewing and photographing density gradients in the test section. Because of the very low test-section pressures in the HWT, the entire light path of the HWT system is enclosed in a tube which is evacuated to test-section static pressure; this procedure nearly eliminates the adverse effects on flow visualization caused by convection currents in the room and at the warm tunnel windows. Models may be front-lighted for schlieren photos in the 20-in. SWT as shown in Fig. E-1. A sample schlieren photo from the HWT is shown in Fig. E-2. High-speed continuous photography at 120 to 7000 frames/sec for recording inlet flow phenomena, ablation of ice-models, etc., is possible in both tunnels. In addition, still and continuous photography can be recorded in either black and white or color in both tunnels. Polaroid camera equipment is available for situations in which it is impractical to wait one day for ordinary JPL film processing.

2. Shadowgraphs may be made using the schlieren light source on film sizes ranging up to 11 x 14 in. Film plates larger than 4 x 5 are exposed while held in place at one of the test-section windows.

b. Visual Indicators

1. The sublimation of azobenzene can be used in the SWT to provide an indication of boundary-layer transition on a model.

2. The "glow probe" technique is available for use in either tunnel, wherein an electric arc ionizes the air between the probe and a model; the results can be seen and photographed by ordinary means through a test-section window. The technique is capable of indicating flow in the low-pressure regions where the normal schlieren system has little or no resolution.

3. The vapor screen technique which uses condensed air or supply air with a high water content with a light screen can be applied in the SWT.

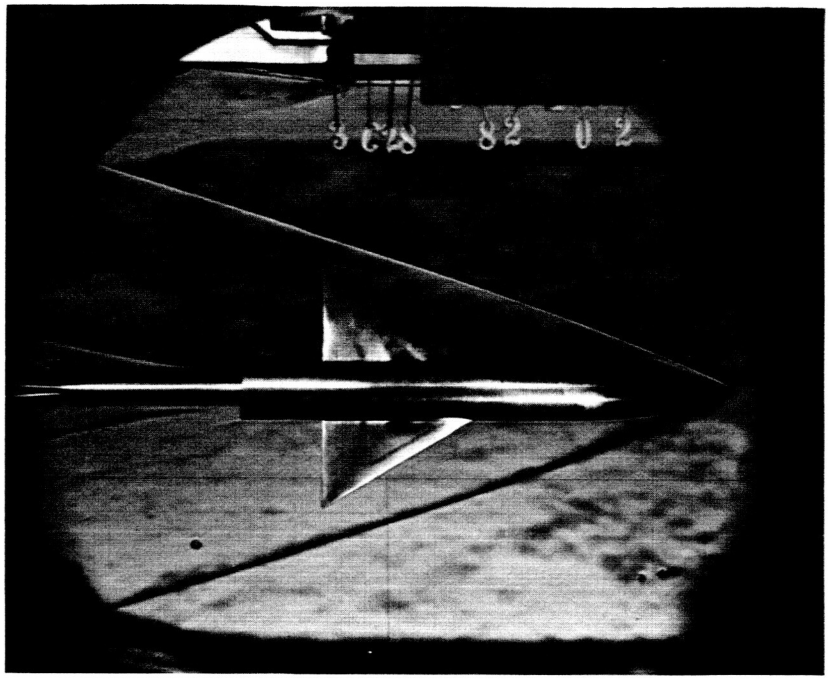

Fig. E-1. Front-lighted schlieren photograph from the 20-in. SWT at M = 5

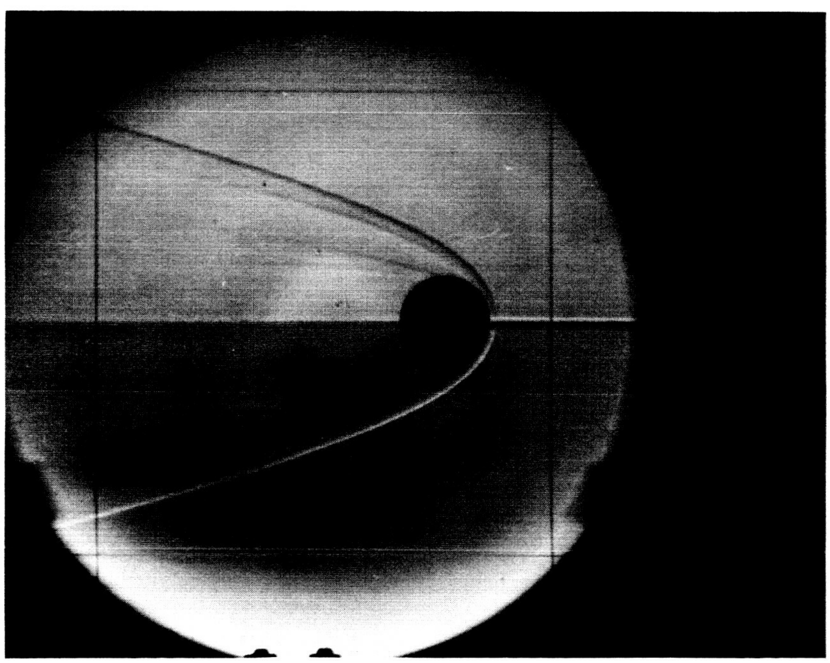

Fig. E-2. Schlieren photograph of wire-supported sphere at M = 7.25 in the 21-in. HWT

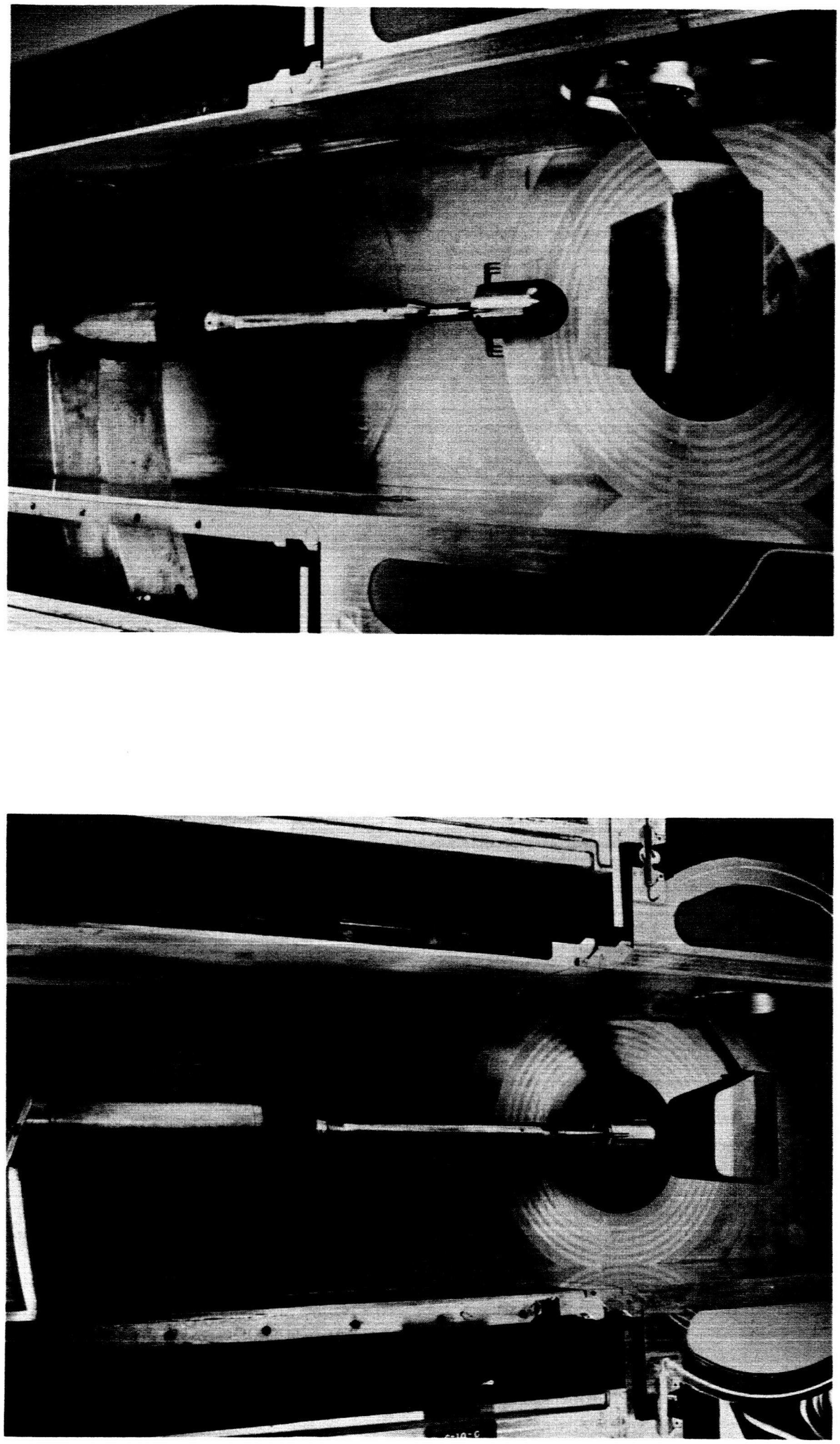

Fig. E-3. Cooling shield in position to exhaust N_2 over a simple model in the 21-in. HWT

F. DATA HANDLING

I. Accumulation

The data output of all instrumentation is converted to digital form, either by automatic digitizers on the instruments or by manually inserting the information in keyboards. A point of data consists of the automatic sequential scanning of all these digitized sources of information by an electronic switching device. The scanning system converts the digitized information to a code which is punched on paper tape. This paper tape serves as a storage medium for the raw data.

The raw data can be examined for validity and consistency by tabulating the data, and by the use of a raw data plotter. The tabulating printer and the plotter both receive the information by reading the punched paper tape. The raw data plotter will plot any twelve channels of data against any other single channel, and is shown in Fig. F-1.

II. Reduction

The data are transmitted from the tunnel console area to the data reduction area electrically from a punched paper tape reader in the console. At this point an ElectroData digital computer, which is shown in Fig. F-1, does "on-line" computing or punches a tape for storage. The computer will handle almost any data-reduction request. A limitation is placed on data reductions, however, to reduce data only to conditions as determined by wind tunnel parameters and model parameter constants. In addition an IBM 7090 computer is available for reducing data recorded on magnetic tape such as transient heat

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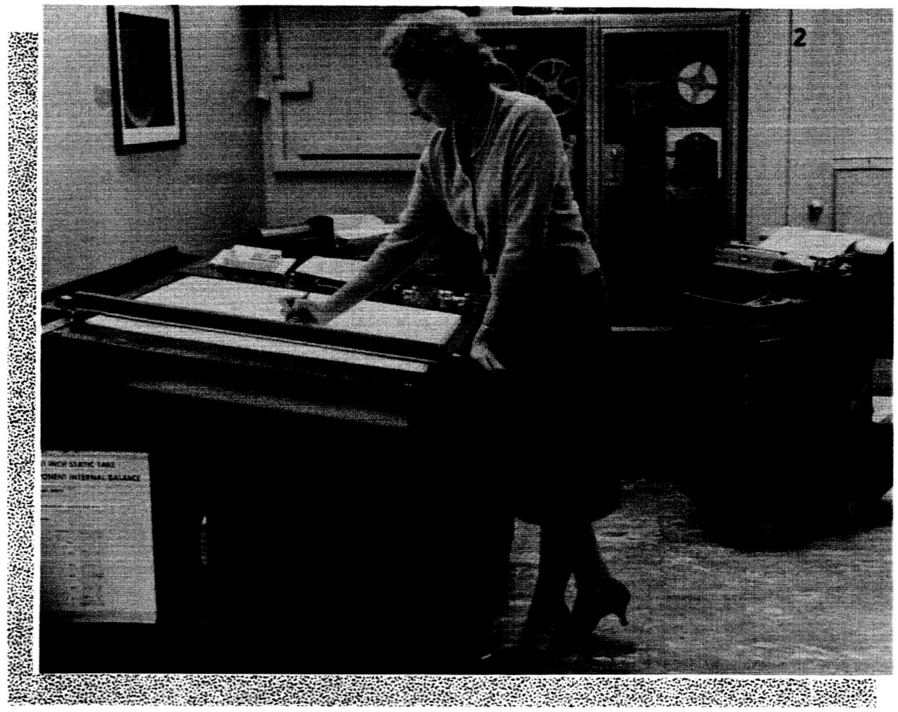
transfer data. Since the wind tunnels operate simultaneously, and only the ElectroData computer is available on a full-time basis, it is necessary to limit "on-line" computing to one test at a time.

III. Presentation

The final reduced data is received in tabular form from the computer. If the test reduction is "on-line", the data are tabulated remotely in the console area. The computer also generates a paper tape which is the input for a set of six plotters located in the 20-in. SWT console area. These plotters are used for "semi-on-line" plotting and will plot up to nine components of final data from whichever tunnel is "on-line". The plotters are shown in Fig. F-1.

One set of final data is either automatically or hand plotted for each test. These plots are then presented in a final data report which describes the model, the conditions at which the test was conducted and states the observed validity of the data.

Raw data plotting



ElectroData digital computer

Final data plotting

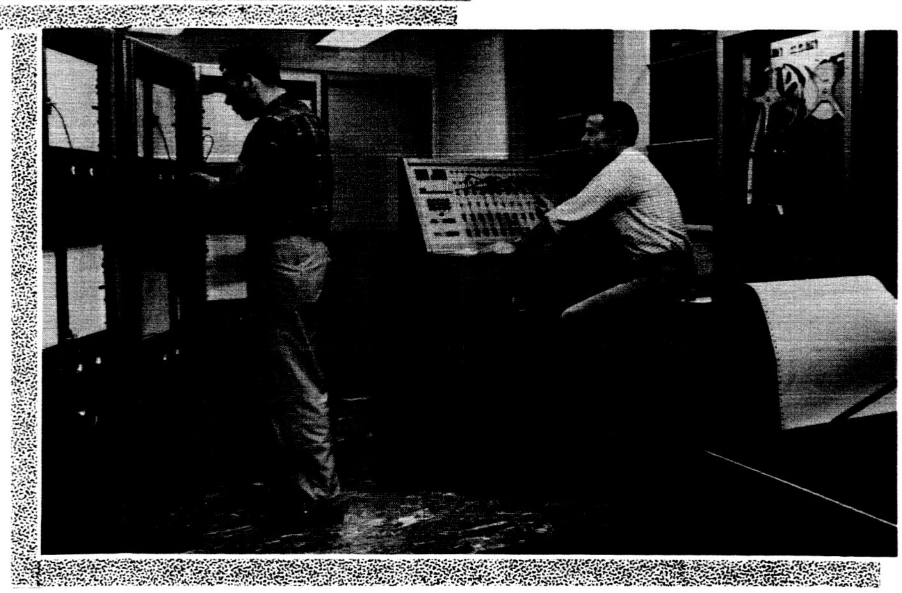


Fig. F-1. Data handling equipment

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APPENDIX I. JPL SERVICES

JPL provides a variety of services to programs that are run in the wind tunnels to ensure efficient use of the tunnels. After the preliminary planning has taken place and a test is scheduled, a project engineer from the Test Projects Group is assigned to the test. The project engineer's duties include (1) coordinating the JPL and contractor (i.e., the person or company for which the test is being run) work, (2) collecting test data, (3) reducing test data, and (4) writing a test report as described in Sect. F. The project engineer has at his disposal a set-up group for test preparation and the JPL photography department to take model and equipment photographs and process these pictures along with flow photographs; in addition, the project engineer may call upon machine shop and instrumentation facilities in the wind tunnel area to perform emergency model and instrumentation work.

In an effort to avoid an undue amount of detail in this general introduction to the JPL wind tunnel facilities, there are a number of special test and instrumentation capabilities which have not been mentioned. Consequently the contractor is encouraged to be inquiring and to take advantage of JPL wind tunnel experience to help him accomplish unique and/or difficult test requirements.

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APPENDIX II.

To: Wind Tunnel Contractors From: Robert E. Covey Revised: 1-1-62

Subject: Required Pre-Test Information

Listed below are the items required by JPL prior to the conduct of each wind tunnel test. A pre-test conference will be scheduled approximately two weeks prior to the start of each test period, at the convenience of the contractor. Items (1) through (5) and (10) below should be transmitted (by mail or by hand) prior to the conference to the following address:

Jet Propulsion Laboratory
California Institute of Technology
4800 Oak Grove Drive
Pasadena 3, California

Attention: Mr. Richard D. Wood

One week later, items (6) and (7) should be transmitted to the same address. Item (8) (models and test equipment) should be addressed to the attention of Mr. Harold P. Holway.

Two Weeks Prior to Test

Item	No. of Copies	
1.	3	Pre-test report containing the following:

a. Statement of purpose of the test

b. Run schedule

c. Range and increments of variable parameters

d. Points at which optical flow visualization photos are desired

Two Weeks Prior to Test (Cont'd)

Item	No. of Copies	
1. (Cont'd)	3	e. Relative priority of various runs
		f. Model configuration notation
		g. Definitions of model surface deflections
		h. Description of pressure orifice location and identification
		i. Manometer key
		j. Description of any special test techniques
		k. Estimate of maximum aerodynamic forces and moments about the applicable balance reference point, and an estimate of the variations within these maxima due to model surface deflections and/or configuration changes
		l. Definition of axis system to be used in presenting data
		m. Definition of reference lengths and areas to be used in reducing data to coefficient form and definitions of pressure coefficients desired
		n. Specification showing desired form of plotted data presentation
		o. Model drawing list
2.	2	Model installation assembly drawings*

*The contractor should indicate how these drawings may be disposed of after completion of the test.

Two Weeks Prior to Test (Cont'd)

Item	No. of Copies	
3.	2	All model drawings*
4.	2	Stress reports (to JPL requirements)
5.	1	List of contractor employees who are expected to visit JPL in connection with the test so that clearances may be checked and authorization for badges may be established at the west gate, thus making it possible for the Contractor to enter the Laboratory outside of the working hours of the Security Office (8:00 a.m. to 4:30 p.m., Monday through Friday).

One Week Prior to Test

Item	No. of Copies	
6.	2	Results of model deflection and internal balance calibrations performed prior to shipping model
7.	2	Inspection report or equivalent for verification of model dimensions, alignment, and settings of model surfaces
8.	1	All model parts, photographic equipment and associated test instrumentation (with "shipping" paperwork)
9.	-	Model mechanic, engineer, and electronic technician (if applicable) to work with JPL set-up crew during pre-test preparation and model installation

*The contractor should indicate how these drawings may be disposed of after completion of the test.

Special Costs

Item	No. of Copies	
10.	3	In order for JPL to complete a wind tunnel test which requires a material expenditure beyond that budgeted for annually, it is necessary for JPL to charge the Contractor for this special expense. Occasional special costs are determined by JPL prior to the pre-test conference. To facilitate collection by JPL of any special costs, it is necessary for the contractor to complete the following requirements on or before the date of the pre-test conference.

1. The Contractor will submit a letter to JPL (Attention: Mr. Richard D. Wood) requesting that JPL furnish the material responsible for the special cost.
2. This letter will specify the quantity of material needed and include a purchase order number against which JPL will charge the material.

REFERENCES

1. Schurmeier, H. M., Design and Operation of a Continuous-Flow Hypersonic Wind Tunnel Using a Two-Dimensional Nozzle, Agardograph 38, May 1959.

2. Riise, H. N., Flexible-Plate Nozzle Design for Two-Dimensional Supersonic Wind Tunnels, Report No. 20-74, Jet Propulsion Laboratory, Pasadena, California, June 9, 1954.